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Preface

The epiSTEME-5 Conference is the fifth in a series of biennial conferences organised by the Homi Bhabha Centre for Science Education, a National Centre of the Tata Institute of Fundamental Research, Mumbai, India. The epiSTEME conferences bring together researchers in science, technology and mathematics education in an interdisciplinary exchange. Research presented in the epiSTEME conferences is inspired by cognitive, pedagogical, historical, philosophical and socio-cultural aspects of the sciences.

Science, technology and mathematics education (STME) have, in recent decades, emerged as lively new research areas. This research, inspired by issues of learning and teaching, has clear uniting themes in the cognitive, pedagogical, historical, philosophical and socio-cultural aspects of the sciences. The epiSTEME conferences occupy a unique position among conferences and bring together researchers in these foundational areas as well as from the domains of science, design and technology and mathematics education. Conference epiSTEME-5 continues this tradition of interdisciplinary exchange.

The name epiSTEME connotes, at one level, a systematic study of knowledge, while as an acronym it suggests a meta-view of science, technology and mathematics education. The previous epiSTEME conferences, held in 2004, 2007, 2009 and 2011 have catalyzed collaborative programmes among researchers and educational practitioners in India and abroad. Within India, they have helped to initiate and foster linkages between theory, empirical research and the activities of grassroot organizations.

During this conference, we are also co-hosting the 20th International Conference on Conceptual Structures (ICCS), from January 10-12, 2013. The special theme for this year for this parallel conference will be "Conceptual Structures for STEM Research and Research". During epiSTEME 5 we have organized a common session to facilitate the exchange of ideas among the two research communities. We are happy to note that epiSTEME-5 has attracted a satellite event around it. We do hope the trend will continue.

Four broad strands of research that impact STME has formed the core of epiSTEME- 5 and themes were identified under each strand to reflect active research topics and areas of interest. These are:

Strand 1. Historical, philosophical and socio-cultural studies of STM: Implications for education *(History and Philosophy of STM, Socio-cultural and gender issues in STM, Science and Technology Studies, Public understanding of and participation in STM)*

Strand 2. Cognitive and affective studies of STME *(Visuo-spatial thinking, Knowledge representation and Conceptual Structures, Language and learning, Problem solving, learning and reasoning, Model based reasoning)*

Strand 3. Curriculum and pedagogical studies in STM *(Assessment and evaluation, Classroom interaction and discourse, Affective aspects of learning, Teacher professional development, Educational initiatives and innovations)*

Strand 4: Information and Communication Technologies in STME *(Open Education Resources, Online and asynchronous learning, Visualization of models and data, Open and Citizen science initiatives)*

Leading scholars from Asia, Africa, the Americas, Australia and Europe present overviews of some of the themes within each strand. We have 9 review talks addressing the research areas of STME. In addition, there are paper and poster sessions. The epiSTEME 5 conference received over 127 submissions. A preprocessing of submissions eliminated 30 papers that were inappropriate or failed to meet the conference guidelines. The remaining 97 submissions were sent to at least two reviewers for blind review. A list of reviewers is included here. We take this opportunity to thank all the reviewers for their role in the peer review process. We accepted 63 papers, half of which were for oral presentation and the rest for poster mode. Authors of only 57 papers only 57 could register for the conference at the time of printing this proceedings. Some of them could not obtain financial support to travel to India, and one of them could not obtain visa to attend the conference.

The participants to epiSTEME 5 come from about 12 countries, besides India. These include Australia, Germany, Greece, Japan, Mauritius, Nigeria, Norway, South Africa, Taiwan, UK, Venezuela and USA.

We wish to express our gratitude towards all members of HBCSE for their co-operation. We thank Prof. Jayashree Ramadas, who has been a source of constant encouragement and Prof. Chitra Natarajan for her support and following up on each and every aspect of the conference organization. All the academic and organisational committee members, the secretariat and the administration headed by Madhavi Gaitonde deserve a special mention for their willing participation in the planning and execution stages. Special thanks is due to Noopura Pathare, who worked on the conference secretariat that helped the event take off. We thank Rupesh Nichat and Anil Kumar Sankhwar for installing and managing the conference website. K. R. Manoj Nair for his help in setting up the payment gateway, and DTP work of the proceedings.

Nagarjuna G.,

Arvind Jamakhandi,

January 2013

Ebie M. Sam

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Review Talks

Developing Pre-service Science Teachers' Ability: Integrating ICT and Teaching

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There is little doubt that science teaching is recognized as an esteemed profession the world over, however, what constitutes the professionalism of science teachers has been long debated; this issue, to some extent, influences the requirements for becoming a science teacher as well as the philosophy and system of science teacher education across generations. I would like to take a historical perspective, to inquire this issue, and envision what a science teacher should be like in the next generation.

In his 1985 presidential address, at the annual meeting of the American Educational Research Association, Lee Shulman, traced back the meanings of "master" and "doctor," which are the highest degrees awarded in any university. It can be found that, centuries ago, the universities were principally normal schools, and "master" and "doctor" had the same definition: "teacher." It is clear that a teacher should have expertise in the subject matter he/she studied and able to make the subject matter learnable for students. That is to say, for a science teacher, the subject matter to be taught, and pedagogy, are parts of one indistinguishable body of understanding. However, as indicated by Shulman, in the spirit of the 1870s, the pedagogy was essentially ignored; the evaluation of teachers in America only emphasized teachers' subject-matter expertise. It is a truth that demonstrating students with knowledge of the subject matter to be taught should be a prerequisite to teaching; but, in this situation what is the difference between being a scientific literate man and being a science teacher? In the 1980s, the evaluation of teachers in America shifted focus to the teachers' capacity to teach. The knowledge of the theories and methods of teaching became the core of teacher assessment. However, this shifting caused a negative image for teaching profession: those who know, do; those who cannot do, but know some teaching procedures, teach. Shulman argued that identifying teaching competence with pedagogy alone is incomplete. For instance, how do teachers decide what to teach, how to represent the content, how to question students about the content and how to deal with problems of misunderstanding, these pedagogical considerations must be processed with the subject matter to be taught. Therefore, in the late 1980s, Shulman coined the term "Pedagogical Content Knowledge" with the attempt to avert the sharp distinction between content (the subject matter to be taught) and pedagogic process. PCK represents the pedagogical understanding of subject matter, and be recognized as the core of teaching profession in the research community of teacher education.

Nowadays, leveraging technologies to facilitate students in conducting a scientific inquiry has been widely regarded as an important trend in education worldwide. We must be conscious of that, in this trend, science teachers are obligated to expend pedagogical knowledge base, rather than to purse fancy technology innovation. Aligning with the current vision of the science education community (e.g., American Association for the Advancement of Science & National Research Council), the use of technologies is expected to assist students in connecting the subject matter: arousing questions to learning; using a variety of learning strategies in solving problems and examining ideas; interpreting their own findings and inquiries; and exchanging thoughts with peers and teachers. The role of science teachers should be facilitators to urge students to become responsible for their own learning. Clearly, the image of the science teaching profession in the contemporary society is expected to adopt a new element: being able to update pedagogy with modern technologies. Mishra & Koehler (2006) and Niess (2005) extended Shulman's notion of PCK to Technological Pedagogical Content Knowledge (TPCK or TPACK). Although the components and epistemological stands of TPACK are still opening to debate, the conceptualization of TPACK is useful for us as a starting point to rethink the core idea of the science teaching profession in the 21st century.

In the past two years, my research team and I have endeavored to develop a pragmatic approach to provide Taiwanese science teachers with a meaningful context in which the innovative technologies can be pedagogically situated in science teaching (c.f., Chang, Chien, Chang & Lin, 2012; Chien, Chang, Yeh, & Chang, 2012). Based on the theoretical framework of cognitive apprenticeship, the 4-phase cyclic MAGDAIRE model (abbreviated from Modeled Analysis, Guided Development, Articulated Implementation, and Reflected Evaluation) has been constructed. The framework aims to engage pre-service science teachers in collaboratively designing, developing, and implementing technology-infused instructional modules, with the support of a mentoring team which consists of educational researchers, senior teachers, and educational technology developers. This process moves pre-service science teachers from the roles of passive users of the innovative technologies into active designers, content providers, and practitioners of technology-infused science teaching. The effectiveness of the MAGDAIRE model, in terms of to improve pre-service teachers' self-efficacy, knowledge, and skills through use of the innovative technologies, has been validated in the aforementioned research. The MAGDAIRE model can facilitate pre-service teachers' critical reexamination of the affordances of the innovative technologies for their teaching practices from the views of subject matter selection, motivation empowerment, information presentation, activity design, and pedagogy transition. It is also found that the MAGDAIRE model can facilitate pre-service teachers' TPACK towards a more connected model that addresses innovative technologies, pedagogy, and subject matter jointly. During my presentation, I would like to introduce you to the MAGDAIRE model, and the related research conducted over the last 3 years. It is our sincere hope that MAGDAIRE will become the next driving force to transform teacher education programs during the 21st century in Taiwan.

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Science and Science Education through the Lens of Diversity

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Science, science education and diversity are intricately bound to each other, and affect one another separately and in combination. Yet they are often researched independently of each other. As pointed by Lee and Luykx (2006), one cannot simply separate out the influences of diversity on students' science attitudes since the relations between different dimensions of diversity are complex.

Research in the fields of science and diversity especially critical epistemology and feminist views have put forth the idea that the inclusion of diverse individuals in the development of science could have changed what is included as important for study and hence the nature of present day science (Bleier, 1986). Studies in science education have addressed the conflict or consensus of scientific ideas with existing cultural ideas (Reiss, 2010). Research in this area includes how diversity intersects with the teaching and learning of science. The relationship between science education and diversity may be viewed through any of several lenses. There is a view that addressing diversity in science teaching is unnecessary. This may be motivated by the belief that science is value-free and universal, and scientific knowledge is intended to be part of the common culture, or that curricula and pedagogy need to be uniform for reasons related to national integration. Another view cites pedagogical reasons for highlighting the differences and acknowledging them in science classrooms. It suggests that curricula should be local specific and motivated by interests of diverse groups.

India, the largest democracy with close to 17% of the world's population has diversities of regions, religions, languages, ethnicity and castes besides the urban-rural and socio-economic divides. India's skewed sex ratio with only 940 women per 1000 men and the national child sex ratio at 914 highlights the gender disparities. All these diversities are manifested in a typical Indian classroom to varying degrees. The education system of India with a large multicultural school going population faces challenges different from those faced by nations with relatively small or homogeneous population.

The curriculum frameworks generated from Independent India to the present have emphasised the need to impart education in an inclusive manner. India’s National Policy on Education (NPE) 1968, 1986, and National Curriculum Framework (2005) have attempted to address imbalances in the education of girls, minority groups, physically and mentally challenged individuals and rural students. Most recently the 'Right of Children to Free and Compulsory Education Act', that came into force in April 2010 provides for free and compulsory education to all children who fall in the age group of six to fourteen years (GOI, 2010).

Attitudinal studies in the context of science education at the Homi Bhabha Centre for Science Education have covered a wide range and have centred around exploration of students' and teachers' attitudes towards science, mathematics technology and design among other school subjects, their ideas about science and scientists, textbooks and nature of science. Work has has also focused on science literacy and career aspirations that students perceive in science and related fields. However, while there has been concern over diversity and its relation to science and science education, it still requires greater attention. Studies in education need to span various diversity parameters like ethnicity, race, region, religion, language, gender, socio-economic status, rural-urban habitat and general cultural differences.

The Homi Bhabha Centre for Science Education (TIFR) has carried out several projects that explored diversity and science education including the study of occupational choices of first generation learners, impact of science education on the role perception of socio-economically deprived first generation learners, students' ideas about science and scientists, effects of language simplification, science communication in regional languages, and exploring how technology can be implemented in rural schools. Exhibitions on Gender and Science and History of Science developed by HBCSE highlight the role of women in science and contributions to science from all cultures, respectively. Recently, a European Union sponsored project 'Science Education for Diversity' has been initiated in six partner countries of which India is one. The project is aimed at understanding the dynamics of the relationships between *culture, ethnicity, religion, socio-economic status* and *gender* in each country. This project has also designed new approaches to teaching science which emphasise the multiple voices in classrooms. It is hoped that inclusive science education can in turn contribute to making the practice of science sensitive to diversity, and attract diverse groups to science and scientific careers.

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Beyond Epistemic Poverty in Science Teacher Development

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Despite decades of arguments for the inclusion of epistemic practices of science in science education, the incorporation of models of knowledge and knowledge growth in science teacher education has been minimal. There is substantial body of literature on science teachers' professional development. Part of this literature focuses on models of teachers' professional development which are often based on a belief that learning to teach is a linear process and that educational change is a "natural consequence of receiving well-written and comprehensive instructional materials" (Hoban, 2002, p. 13). However for continuing professional development (CPD) to be effective, a more complex view of professional development is required. Educational change is complex and it takes time (Fullan, 2001). Furthermore, fundamental and substantial changes cannot be achieved within a short period of time. Supovitz and Turner (2000) identify as critical to high-quality professional development the following features: immerse participants in inquiry, questioning and experimentation; be intensive and sustained; engage teachers in concrete teaching tasks and be based on teachers' experiences with students; focus on subject-matter knowledge and deepen teachers' content skills; be grounded in a common set of professional development standards and show teachers how to connect their work to specific standards; and be connected to other aspects of school change. Duschl & Erduran (1996) suggested that professional development programmes integrate models of epistemic practices in science. Epistemic practices are the cognitive and discursive activities that are targeted in science education to develop epistemic understanding (e.g. Sandoval et al., 2000). These practices include the articulation and evaluation of knowledge; coordination of theory and evidence; making sense of patterns in data; and holding claims accountable to evidence and criteria. The application of epistemic perspectives on science in teachers' learning communities puts additional demands on teacher educators. Epistemic practices are relatively unfamiliar aspects of science for teachers as well as the teacher educators themselves. In anticipating the practical realities of the science classroom, the relevance and applicability of models of knowledge growth are often questioned and abandoned in professional development programmes. The outcome for both teachers' development and eventual pupils' learning is "epistemic poverty," a kind of exclusion and deprivation in the landscape of scientific knowledge in schooling. One of the consequences of such epistemic poverty is the lack of understanding and appreciation of how knowledge is generated, evaluated and revised in science.

The presentation will provide a theoretical overview of epistemic practices in science in particular focusing on the disciplinary context of chemistry (Erduran, Aduriz-Bravo & Mamlok-Naaman, 2007). Some recent developments from the field of philosophy of chemistry will be used to illlustrate the significant epistemic aspects of science with simplifications for science education in general (e.g. Erduran & Mugaloglu, 2013) and for teacher education in particular. Example perspectives and models of scientific knowledge and knowledge growth will be reviewed. For example, theoretical and empirical work on argumentation (i.e. coordination of evidence and theory) as an epistemic practice will be detailed to provide an instance of how epistemic practices of science can be infused in science teaching, learning and professional development. There are at least four theoretical bodies framing argumentation studies: developmental psychology, including the distributed cognition perspective; philosophy, as for instance the theory of communicative action; language sciences; and science studies, that is history, philosophy and sociology of science. The work of science educators has drawn on a range of perspectives on argument and argumentation (e.g. van Eemeren et al., 1996; Perelman & Olbrechts-Tyteca, 1958; Toulmin, 1958; Walton, 1996), as well as linguistic perspectives on discourse and communication (e.g., Bronckart, 1996; Grize, 1996). The research emphasis in science education has typically concentrated on definition of argument based on the work by Stephen Toulmin (e.g. Erduran, Simon, & Osborne, 2004) whilst the use of Douglas Walton's model has been relatively minimal in science education across the world at large (e.g. Duschl, 2008) and in Europe in particular (e.g. Jiménez-Aleixandre, Agraso & Eirexas, 2004; Ozdem, Cakiroglu, Ertepinar, & Erduran, in press). Whilst these two models have often been presented as a contrast to each other, it is worthwhile to highlight that they actually address different aspects of argument and argumentation (Erduran, 2008). Toulmin's framework concentrates on the components of an argument whereas Walton's schemes detail different types of arguments. The presentation will include examples from a range of school-based research project to highlight the implementation of argumentation in secondary schools. For example, the case of the European Union funded STEAM project will be used to highlight how inquiry-based science teaching (IBST) has been promoted in the context of argumentation. The aspect of IBST – argumentation - was selected as a theme to investigate with teachers in England because this theme has recently been promoted in the English National Science Curriculum (DfES/QCA, 2006) under the "How Science Works" agenda. The focus has been on ways in which teachers supported processes stemming from their classroom cultures, including the facilitation of student discussions, practical work and understanding of the processes of science. The CPD model offers the opportunity to construct a forum for deliberation about practice that contrasted with the norm of privacy that dominates most schools (Spillane, 1999). To this end, the university researchers participating in the project encouraged peer reflections and sharing of lesson resources across schools.

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History and Philosophy of Science as a Guide to Understanding Nature of Science

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The nature of science is highly topical among science educators and increasingly it is becoming a mandated topic in science curricula in various countries. It is plausible to suggest that those who do science, study science and teach science must understand the nature of science (NOS). However, research in science, philosophy of science and science education shows that this is not always the case. The objective of this review is to present, compare and critique NOS views of scientists, philosophers of science and science educators, in order to provide guidelines to the practicing teacher. Weinberg (2001), Nobel Laureate in physics conceptualizes nature of science as: "What drives us onward in the work of science is precisely the sense that there are *truths out there to be discovered*, truths that once discovered will form a permanent part of human knowledge" (p. 126, emphasis added). Giere (2006), a philosopher of science has characterized such philosophical positions as "objectivist realism" and argued cogently, "… Weinberg should not need reminding that, at the end of the nineteenth century, physicists were as justified as they could possibly be in thinking that classical mechanics was objectively true. That confidence was shattered by the eventual success of relativity theory and quantum mechanics a generation later" (p. 18).

Let us now consider the NOS views of science educators. Despite continuing controversy some degree of consensus has been achieved in the science education community with respect to the following aspects of NOS (Abd-El-Khalick, 2012; Lederman et al. 2002; Niaz, 2009a, 2012): 1) Scientific knowledge relies heavily, but not entirely, on observation, experimental evidence, rational arguments and skepticism; 2) Observations are theory-laden; 3) Science is tentative / fallible; 4) There is no one way to do science and hence no universal, recipe like, step-by-step scientific method can be followed; 5) Laws and theories serve different roles in science and hence theories do not become laws even with additional evidence; 6) Scientific progress is characterized by competition among rival theories; 7) Different scientists can interpret the same experimental data in more than one way; 8) Development of scientific theories at times is based on inconsistent foundations; 9) Scientists require accurate record keeping, peer review and replicability; 10) Scientists are creative and often resort to imagination and speculation; 11) Scientific ideas are affected by their social and historical milieu. Duschl and Grandy (2012) have questioned the use of benchmarked domain-general, consensus based aspects of NOS as presented above. These authors have adopted a naturalistic account, which they claim goes beyond the historical turn in the philosophy of science, to explain the emergence of new conceptual (what we know), methodological (how we know), and epistemological (why we believe) standards for the growth of scientific knowledge. Furthermore they have argued that recent science has been more successful in achieving 'true theories,' which approximates to the thesis advocated by Weinberg. Matthews (2012) has also critiqued the NOS consensus lists and suggested an approach that is more consonant with historical and philosophical developments. A novel feature of this approach is the proposal to adopt 'Features of Science' (FOS) instead of NOS that are "more relaxed, contextual and heterogeneous" (p. 3), based on the following items: 1) Empirical basis; 2) Scientific theories and laws; 3) Creativity; 4) Theory dependence; 5) Cultural embeddedness; 6) Scientific method; 7) Tentativeness. Even a cursory glance would show that there is a fair amount of overlap between the 11 NOS aspects and the 7 FOS items.

Besides the characterization of progress in science as NOS or FOS, it is important to explore how history and philosophy of science (HPS) can be incorporated in the science curriculum and thus facilitate students' and teachers' conceptual understanding. Wilson, Nobel Laureate in physics has posed an interesting question, "Does science education need the history of science?" and responded in the affirmative (Gooday et al. 2008). The historical perspective inevitably leads to an analysis of how science is practiced by scientists (Niaz, 2010), which involves presuppositions of the scientists, alternative interpretations of data, controversies among scientists having similar experimental data, and inconsistencies involved in the construction of a theory. On the contrary, most science curricula and textbooks in different parts of the world emphasize "rhetoric of conclusions" (Schwab, 1962), in which science is presented as a list of empirical findings and irrevocable truths. In contrast, Niaz (2009b) has shown that given the opportunity to reflect, discuss and participate in a series of course activities based on various controversial episodes (atomic structure, oil drop experiment, kinetic theory, covalent bond), teachers' understanding of NOS can be enhanced. Finally, inclusion of NOS and HPS can motivate students to study science and form part of a responsible citizenry (Hodson, 2009).

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Outcomes of a Learning Society – Democracy and Secularism

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Debates and discussions about learning outcomes from education are understandably endless. In recent times, the results of PISA and ASER tests have fuelled the notion that the learning outcomes of Indian children are woefully inadequate in areas like mathematics and languages. Various interest groups use such results to strengthen their respective perspectives and arguments about education; for example, those advocating greater access to market forces in education cite these results as proof that the government can not deliver education of good quality, thereby seeking a withdrawal of government schooling in favour of private schooling.

The question we however need to ask is: Important though it is that children learn various subjects in school with competence, is that all there is to education? Does that fulfil the ultimate objective of education? It has become necessary to raise such questions because of an increased stress on reducing education to developing skills necessary for the labour market, or at best enhancing only the cognitive abilities of children, as depicted by their performance in subjects related to science, technology and mathematics.

Do these outcomes fulfil the demands of a Learning Society? In particular, what should be the ultimate purpose of education and learning in a country with such a vast economic, social, cultural and linguistic diversity as it exists in India? Just as we tend to take the basis of life, the heart beat, for granted, without really bothering to go deep into the complexities of what makes a heart beat, it often escapes our attention as to what made this diverse land and its diverse people – India – transform from fragmented monarchies and colonialism into a democratic nation-state. With perhaps less diversity than India, Europe consists of nearly thirty independent nation-states. Given that India has 22 official languages, people from seven religions, a diverse tribal population of around 80 million, by all empirical notions of nationhood, the pre colonial India instead of being broken into three, India, Pakistan and Bangladesh, should perhaps have another 20 or more independent nations. That it did not happen speaks volumes of the great thinkers and practitioners of our freedom movement who crafted a constitution that saw only one fragment separating, namely Pakistan, and the rest of the people accepting to remain together as fellow-citizens under a single constitution. A closer study of the process of formation of India's nationhood would reveal that the two pillars on which this single nation stands, and are embodied in its constitution are Democracy and Secularism. Democracy guarantees the rights of its diverse citizens and Secularism protects people of diverse religions. Without these guarantees in the constitution, India as it exists today would not have been possible.

So what is the link between education and such processes of nationhood that go beyond good learning outcomes in school subjects? The first is to recognise that the process of forming the nation is not over till a majority of people feel their rights to life, expression, identity education, health and gainful employment have been fulfilled. The reductionist notion of education, to prepare a child for the labour market might fulfil one of these needs, namely that of gainful employment; but to think that education has little to do with the rest is a dangerous illusion. For example:

- Unless people feel that their right to equal opportunity to quality education has not been fulfilled, the deprived sections are bound to feel exploited; that they did not benefit by being citizens of this single nation.
- The practice of democracy is based on an ability to engage with debate with people who hold contrary views and opinions. In a diverse country like India, diverse views and opinions are axiomatic. To prepare minds that can negotiate such differences is the basic necessary element in sustaining the nation-state. The intolerance one witnesses in the country, with accompanying violence in many cases has many roots, 'bad' education, one can argue is one of them.

Historically, the journey from a feudal state where most of the people are slaves, to monarchy where people are subjects, to a democratic nation-state where people are citizens with rights has been difficult; education having been the most important catalyst and lubricant of such transformation. This journey is ongoing in India, and one could argue that it is so because education has not been crafted properly to accomplish this journey. Some of these shortcomings are:

- The absence of a right to education of equitable quality. The demand was raised as early as in 1882, but became a reality as late as 2009
- The absence of a proper understanding of how the cognitive and the affective domains of a child need to be stimulated simultaneously so as to produce not only a good scientist or technologist, but a person who can practice democratic values through debate and respect for diversity, sensitive to the needs of fellow citizens and the society. In short, a capable and creative citizen of a country with vast diversities.

Using the author's familiarity with the processes behind the Right to Education Act 2009 and the details of the National Curriculum Framework 2005, the paper will try to analyse and discuss why education has to seek higher goals and outcomes than merely high subject marks, being good in software and English language, in order to produce creative and useful citizens of a country like India; who can then also become productive and effective global citizens.

Integrative STEM Education: Retrospect/Prospect

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"Integrative STEM Education" refers to instructional approaches that intentionally situate STEM[1] teaching and learning in the context of engineering design activity (Sanders, 2006; 2008).[2] There are many reasons for implementing and investigating integrative approaches to STEM education; primary among them is the relatively untested hypothesis that situating science and mathematics learning in the context of engineering design activity might be a more effective way of teaching some S, T, E, and/or M concepts and practices to some or all students at some or all grade levels.

The purpose of this paper is to provide a broad introduction to integrative STEM education. It includes: 1) a more thorough explanation of integrative STEM education than provided above; 2) an abbreviated description of the historical context leading to integrative STEM education; 3) brief descriptions of an array of emerging 21st century integrative STEM education-related initiatives and research activities that are and/or will be impacting upon STEM education; and 4) a discussion of some perceived implications of integrative STEM education for STEM education.

The school subjects of Science, Technology, Engineering, Mathematics came to the American public school curriculum at different times, from different cultures, and were driven by different goals and aspirations. Not surprisingly, therefore, they have each carved out a separate space in the K-16 curriculum, where they have operated blissfully in almost total isolation ever since. Historically, engineering education was uniquely isolated, as it occurred exclusively in postsecondary education.

Historical precedents for integrative STEM education date to the late 19th century, with each of the STEM subject areas having promoted integrative approaches to STEM education at various times throughout history. In the 1870s, Calvin Woodward, a Mathematics professor with a doctorate from Harvard University wondered if having his students build geometric models (from wood) would enable them to better understand the principles of solid geometry he was teaching. The idea of situating math learning in the context of technological activity worked so well, he established a high school and later the field we now call Technology Education on the basic principle of integrative STEM education (Bennett, 1937). John Dewey, America's most celebrated philosopher of education believed strongly in learning by *doing.* He wrote, "there's no such thing as genuine knowledge and fruitful understanding, except as the offspring of doing" and experimented with labs that provided authentic and integrative learning opportunities (Dewey, 1916). National education reform documents have promoted integrative approaches since the early 1980s. *Science for All Americans*, which has driven Science education reform for more than two decades opened with this *integrative* theme: "It is the union of science, mathematics, and technology that forms the scientific endeavor." (AAAS, 1989). The idea of integrating the teaching and learning of the STEM subjects began to find its legs in the early1990s, as the National Science Foundation and others began funding curriculum projects that sought to integrate the teaching and learning of Mathematics, Science and Technology (e.g., Brusic & Barnes, 1992; Hutchinson, 2002; LaPorte & Sanders, 1996; Satchwell & Loepp, 2002; Project Lead the Way; Scarborough & White, 1994; and Todd, 1999). These early curricula were each grounded in engineering design activity and developed by the Technology Education community, but other design-based integrative STEM curricula followed from the other STEM disciplines. During this same period, researchers began to investigate science taught in the context of technological / engineering design activity (e.g., Roth, 2001; Kolodner, 2002). Their work has begun to illuminate challenges and significant / important benefits associated with design-based STEM education.

1 "STEM education" is used in this paper to refer to the school subjects of Science, Technology, Engineering, and Mathematics. In this paper, "STEM" does not imply any sort of curricular integration or connections among the STEM subject areas, because "STEM" did not imply such connections when NSF coined the term (Sanders, 2008).

2 The more formal "operational definition is: Integrative STEM Education refers to technological / engineering design-based learning approaches that intentionally integrate content and processes of science and/or mathematics education with content and processes of technology / engineering education. Integrative STEM education may be enhanced through further integration with other school subjects, such as language arts, social studies, art, etc." (Sanders, M. E. & Wells, J.G., 2006-2011).

By the turn of the century, the idea of integrative approaches to STEM education was clearly gaining momentum. The publication of *Standards for Technological Literacy: Content for the Study of Technology* (ITEA, 2000) communicated, for the first time, the ideals of Technology Education to STEM educators, administrators, and education policymakers operating outside the field of Technology Education. The *STL* had been reviewed and endorsed by the National Academy of Engineering, and were well received and particularly helpful to those outside the field developing integrative STEM curriculum materials. In 2002, the National Academy of Engineering published the first of three books that each promoted the idea of *integrating* engineering content into "non-technology subjects (Pearson & Young, 2002).

The publication of *The World is Flat* (Friedman, 2005) generated a frenzy of concern regarding the quality of STEM education in the U.S. Those concerns and the rapid emergence of a stunning array of new K-12 engineering-related initiatives (described and discussed in the latter part of this paper) are beginning to impact STEM education in the U.S. in unprecedented ways.

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Cultural Development of Mathematical Ideas

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My purpose in the review lecture is to present a research framework that illuminates the interplay between cultural and cognitive developmental processes in the domain of numerical cognition. I illustrate the framework with studies that focus on the shifting organization of collective practices of economic exchange and schooling through historical time in remote Oksapmin communities in Papua New Guinea. My focus is the dynamic processes that explain the emergence of new forms of collective representations and numerical ideas.

Cultural-developmental Framework

The research framework is both cultural and developmental. It is cultural insofar as the focus is on collective practices, which I define as recurring and semi-stable social organizations that people reproduce and alter in their daily activities and that are furthermore reproduced and altered over time. Economic exchange in Oksapmin trade stores is an example of a collective practice, one in which arithmetical problems -- like the exchange of commodities -- recurs for participants. The framework is also developmental in its focus on shifts in cultural forms of representation and the functions that those forms serve as individuals frame and construct solutions to collective problems of communication and problem solving. I argue that the coordination of these cultural and developmental strands provides considerable leverage in analyzing the emergence, reproduction, and alteration of new representational forms in communities and new functions for such representational forms.

Oksapmin Communities in Papua New Guinea

First contacted by a 1939-1939 Australian patrol that was exploring uncharted areas thought to be uninhabited, the Oksapmin occupy valleys in a rugged highlands region of central New Guinea. The first patrol post and first mission was built in Oksapmin in the 1960s, and the first Western-styled school built of indigenous materials was established in the late 1960s. Western currency was introduced in the context of trade with patrol officers and missionaries, and later exports of vegetables to other parts of Papua New Guinea. In the late 1960s, local people began establishing tradestores. Today the communities remain remote, with no roads to the area, and the cash economy exists alongside the traditional subsistence economy.

I will illustrate the utility of the research framework with examples from my fieldwork in Oksapmin communities in 1978, 1980, and 2001. These visits and the associated studies revealed shifts in collective practices of economic exchange and schooling, as well as related shifts in the reproduction and alteration of cultural forms of representation and the functions that these forms served in exchanges and schooling.

Cultural forms for number representation and shifting functions

In traditional life, the Oksapmin use 27-body parts to represent number. The system does not have a base structure, and the system was not used to serve arithmetical functions. Rather, the system was used to communicate about cardinal numbers of valuables as well as indicate ordinal positions. To count as Oksapmin do, one begins with the thumb on one side of the body and enumerates the names of body parts around the upper periphery through the little finger on the opposite side (see Figure 1). Words for numbers are body part words. With shifting collective practices of exchange, new problems emerged for Oksapmin people that involved arithmetic in collective practices of economic exchange and schooling.

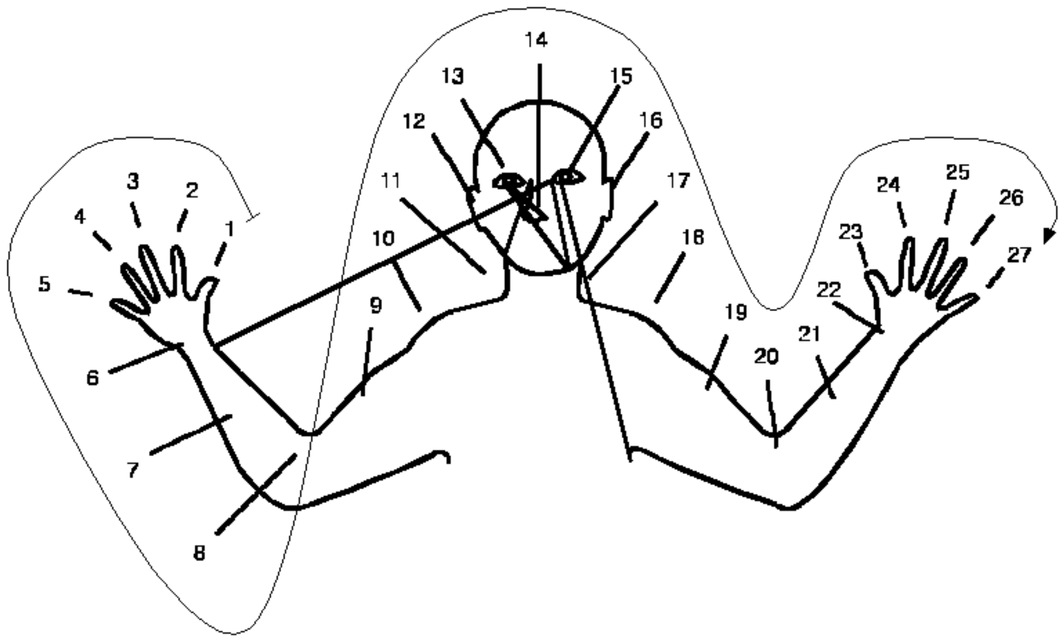

Figure 1. The Oksapmin 27-body part counting system (See http://www.culturecognition.com/ for video of people displaying and using the system.)

In a series of studies conducted across field visits, I documented the shifting collective practices and the emergence of ways the people structured the body system and other representational forms to serve new functions in the community, both for arithmetic problem solving and the representation of currency tokens. The findings that I report were generated from ethnographic studies during each stint of fieldwork related to economic exchange and schooling, cross-cohort studies of people's arithmetical problem solving who had varying levels of participation with the money economy, observational studies of children solving arithmetical problems in Oksapmin classrooms across grade levels, and studies of Oksapmin naming practices for currency tokens and arithmetical composition of tokens across multiple cohorts of Oksapmin people.

Concluding Remark

Psychological studies of culture-cognition relations are often conducted without attention to the interplay between the cognitive activities of individuals and the collective practices with which they participate. The framework that I developed and applied to my Oksapmin studies is a mark departure from longstanding approaches. The Oksapmin case studies reveal ways that people have adapted the body part counting system to serve new numerical functions, producing often unintentional shifts in both the forms of representation and the functions that those representations serve in collective practices. I will suggest how the framework and research methods have applicability for investigations of culture-cognition relations in other cultural contexts, including classrooms and out-of-school practices in technological societies.

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Studying Mathematics Classrooms Cross-culturally

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There has been a greater recognition in mathematics education research community that mathematics classrooms need to be considered as cultural and social environments in which individuals participate, and that teaching and learning activities taking place in these environments should be studied as such (e.g., Cobb & Hodge, 2011). These realizations have led to studies of differences between teaching behaviors and learning outcomes in different countries. Then, similarities and differences have been explored in such topics as mathematics classroom instruction, teachers' mathematics knowledge for teaching, and teachers' perspectives on effective mathematics teaching (Li & Shimizu, 2009, Shimizu & Kaur, in press). With the growing internationalization of education, and as the education community gives higher priority to international research, it is timely to examine the insights from comparative analyses of classrooms that are situated in very different cultures. The contrasts and unexpected similarities offered by cross-cultural studies reveal and challenge existing assumptions and theories.

One of the reasons for studying teaching and learning in classrooms across cultures is that teaching is a cultural activity (Stigler & Hiebert, 1999). Because cultural activities vary little within one community or society, they are often transparent and unnoticed. Cross-cultural comparison is a powerful approach to uncover unnoticed but ubiquitous practices. Comparative study invites examination of the things "taken for granted" in our teaching, as well as suggesting new approaches that never evolved in our own society (Stigler, Gallimore, & Hiebert, 2000). International comparative classroom research is viewed as the exploration of similarity and difference in order that our understanding of what is possible in mathematics classrooms can be expanded by consideration of what constitutes "good practice" in culturally diverse settings. These premise invite researchers to tackle with methodological challenges.

In recent developments in mathematics education, research aims, technological advances, and methodological techniques have diversified, enabling more detailed analyses of learners and learning to take place in mathematics classrooms (Shimizu & Williams, in press). Researchers in the field of mathematics education have recently drawn upon a broader array of theoretical positions and research methods to frame their inquiries. This broadening of research perspectives is closely tied to the emergence of new technological advances that have increased the capacity for large-scale qualitative research methods and analysis applications. Qualitative methodologies have increasingly complemented quantitative methodologies. Increased opportunities to study learners in different cultural, social and political settings have also become available, with ease of access to the classroom data (Stigler & Hiebert, 1999; Clarke, Keitel & Shimizu, 2006).

There are many dichotomies found in cross-cultural studies. The dichotomy "East versus West", for example, has been foregrounded by international benchmark testing, and has led to a qualitative focus on learning in different geographical regions as a result. Accumulated research over the past decade has contributed to our understanding of similarities and differences in mathematics teaching and learning between East Asia and the West (e.g., Leung, Graf & Lopez-Real, 2006) or between Eastern and Western cultures (Cai, 2007). The discussion document for the ICMI study argued that "those based in East Asia and the West seem particularly promising for comparison." In this study a comparison was made between "Chinese/Confucian tradition on one side, and the Greek/Latin/Christian tradition on the other" (Leung, Graf & Lopez-Real, 2006). Juxtaposing the two different cultures indicated that researchers wanted to examine teaching and learning in each cultural context by contrasting differences between them. The labels "East/Eastern" and "West/Western," however, could be problematic in several ways. First, the terms East and West literally mean geographical areas but not cultural regions. Needless to say, there are huge diversities in ethnicity, tools, and habits that are tied to the corresponding cultures. Further, Cobb and Hodge (2011) argue that two different views of culture can be differentiated in the mathematics education literature on the issue of equity, and that both are relevant to the goal of ensuring that all students have access to significant mathematical ideas. "In one view, culture is treated as a characteristic of readily identified and thus circumscribable communities, whereas in the other view it is treated as a set of locally instantiated practices that are dynamic and improvisational" (p. 179). With the second view, in particular, it is problematic to specify different cultures based on geographical areas.

Second, it is possible to oversimplify and mislead the cultural influence on students' learning within each cultural tradition by using the same label for different communities. For example, there are studies that suggests much child education in Japan diverges from the Confucian approach in "East Asia" (Lewis, 1995). Also, in the special issue on exemplary mathematics instruction and its development in selected education systems in East Asia, it was manifested that there are variety of approaches to accomplish quality mathematics instruction in these different systems in East Asia (Li & Shimizu, 2009). Thus, any framework for differentiating cultural traditions runs the risk of oversimplifying the cultural interplay. In particular, there is a need to question whether polarizing descriptors such as "East" and "West," "Asian" and "European," are maximally useful. Perhaps we need more useful ways to examine differences, for the purposes of learning from each other and identifying ways to optimize learner practices.

Mathematics education research in recent years tends to include more international endeavors than ever before. As the globalization and internationalization of research activities has continued to increase, the field of mathematics education research has clearly shown the diversification of perspectives on teaching and learning in classrooms embedded in local contexts. International comparative studies have started to recognize the need to focus on existing diverse voices and perspectives among members of the community.

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Socioscientific Issues as a Socio-cultural Approach to Scientific Literacy

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In recent years, the socioscientific issues (SSI) framework has provided researchers and educators with a viable means to connect students the with the world around them (Mueller, Zeidler, & Jenkins, Spring, 2011; Zeidler, Applebaum & Sadler, 2011), engaging them in the activity of science (Walker, & Zeidler, 2007; Zeidler, Applebaum, & Sadler, 2011), fostering evidence-based reasoning (Applebaum, Zeidler, & Chiodo, 2010), developing nature of science understanding (Eastwood, Sadler, Zeidler, Lewis, Amiri & Applebaum, 2012; Zeidler, Sadler, Applebaum & Callahan, 2009), facilitating scientific literacy (Zeidler & Sadler, (2011), and fostering a sense of ethical caring and character about the social and natural world (Fowler, Zeidler, & Sadler, 2009; Zeidler, Berkowitz & Bennett, 2011; Zeidler & Sadler, 2008). These studies (and others) provide a basis to raise viable questions about whether a singular identity of scientific literacy (or at least what I will argue is the most important feature of any notion of what it means to be scientifically literate) is feasible in a pluralistic world.

To begin, let us raise the obvious question that begs our attention: what does it mean to think in scientifically responsible ways? What does it mean to think globally and act locally if words and deeds are to be viewed in a global context? That we live in a pluralistic world with competing values is brute fact to be reckoned with. Defining what it means to think responsibly in a pluralistic community is both an academically interesting challenge and a task that is necessary to support the quality of our physical, organic and social world. Here, I wish to argue that if we hope to achieve a common vision of sustainability and facilitate public understanding of science, then we will find that thinking in scientifically responsible ways requires features of character, which in turn requires the formation of conscience. For this to happen, there needs to exist a sense of *community* in science education.

All of us recognize the need for future scientists to be insightful and well grounded in their respective research programs. But I am also concerned about the larger majority of students who will not seek scientific professions, but who, nonetheless need to be functionally scientifically literate and make informed judgments about decisions that impact the biological, physical and social environment. Character, at least in the sense that I am prescribing, matters. Character is intricately tied to virtue – a sense of being true to oneself and appearing to others in a manner that is transparent; we appear to be who we really are. Hence, our words and deeds are the signature of our character, and our character is bound up in the actions and perceptions of others in the world.

If the crux of making informed judgments about worldly matters depends on being scientifically literate, and the expression of scientific literacy is defined in terms of responsible decision-making, then we find ourselves in the mist of tautology. To clear the mist, let us consider the following conceptual distinction. We need to ask ourselves if we can imagine a world where one can be properly identified as being scientifically literate, yet bear no responsibility to subsequent decisions made about policy, research, community, family and the like. We would likely agree that such an individual would possess technical competence, but lack the *inclination* to enact that knowledge with due consideration of the world around them. In the alternative, can we imagine a scenario in which one makes consistently responsible decisions that impact the world around us and lacks scientific literacy? We would be hard pressed to imagine such decisions not being *informed* by knowledge of or about science. It would seem that some manner of scientific literacy is a prerequisite to making responsible decisions, though not a sufficient condition for such decisions to occur. While literacy may not require a moral compass, scientific literacy, in the sense that I am prescribing, does.

The recent emphasis on STEM initiatives (NRC, 2011), in many ways, exacerbates the disconnect of sociocultural responsibility from dominant paradigms because it carries with it shades of what Kincheloe & Tobin (2009) would refer to as “crypto-positivism,” where an unexamined set of cultural epistemological beliefs becomes decontextualized and the knowledge derived from those beliefs becomes objectified and generalized (e.g., as in the case of “best practices”) so as to unwittingly endorse the norms and values already dominant in that culture. The failure to appreciate the unique temporal, cultural, economic, and political webs of social matrixes that make up the immediate lives and environments of students’ epistemological views only furthers hegemonic powers. This is precisely where the SSI framework offers a degree of pushback to the unwitting dominant norms of STEM program initiatives. STEM education programs, as typically advocated, fails to be embedded in a coherent developmental or sociological framework that explicitly considers the psychological and epistemological growth of the child and ignores the development of character or virtue. Missing, is explicit attention to socioscientific and sociocultural perspectives central to forming a fully developed sense of scientific identity that necessarily entails moral responsibility (Zeidler, Berkowitz & Bennett, 2012). The SSI framework, as we will find, fulfills this aim, and in the process, can lead to a functional sense of scientific literacy for all.

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Historical, Philosophical and Socio-cultural Studies of STM: Implications for Education

Mathematics and Its Images of the Public

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The paper is an attempt to understand the historical processes by which mathematics and its publics have come to imagine each other in our society, by looking into two different instances from the past. Introducing the kaṇakkatikāram tradition of engaging with mathematics in the Tamil speaking region, we argue how it framed mathematics as both skill and useful knowledge while inviting its public to make themselves clever and prudent. It also claimed for itself a sense of virtuosity through systematic exposition of a theory of its own computational practice. In the second instance discussed, we argue how the institutional components of this tradition became part of a pedagogic apparatus in Europe as well as part of colonial education, while becoming part of a Christian value system of emulation and perseverance while contending with the emergent liberal ethos of education in early nineteenth century Britain.

Introduction

We are often used to stories of how the publics imagine mathematics. And, these are not very pleasant, most of the time. It does not augur well for mathematics if so many people dislike it, to put it mildly. If the distance between a public and a knowledge produces cultural privilege in favour of the knowledge form, in a deeply hierarchical and caste ridden society like ours, it does not serve well the democratic ideals of knowledge. It is important to understand the historical processes by which mathematics and its publics have come to imagine each other in our society. In this paper, I shall, very briefly, make an attempt to reconstruct the nature of the public that mathematics imagined for itself, in two significant moments in the past.

kaṇakkatikāram's Public:

This is a tradition of mathematical practice, active in circulation in the sixteenth and the seventeenth century Tamil region, which was primarily agrarian and mercantile. I shall try to reconstruct the virtues and ideals of mathematics that this tradition, seemed to hold for its public. This tradition is available to us, through texts that survive, as palm-leaf manuscripts in the various repositories in the country and some of them entered the world of print during the nineteenth century. The name *kaṇakkatikāram* does not refer to one particular text, but denotes a genre of texts of the same kind. There are also other texts like the *kaṇita nūl* and *āstāṉa kōlākalam*, both of which have also been edited and published (Subramaniam. P & Kamesvaran. K. S, 1999; Sarma. S, 1951). These texts acknowledge each other's presence pointing to the existence of a system of mathematical knowledge in circulation during the sixteenth century and later.

A typical *kaṇakkatikāram* text had six distinct sections, classified according to the objects of computation rather than the type of operations or techniques. There were sixty types or '*inam*' in as many verses dealing with land (23), gold (20), paddy or grain (6), rice (2), solid stones (3), volume measures (1) and general problems (5) (Kamesvaran. K. S, 1998). Some other *kaṇakkatikāram* texts also have sixty four verses in total. The section on land would deal with various ways to measure areas of land of different dimensions involving magnitudes of whole and fractions. They also had techniques to calculate total produce from an estimated area, assessment of profit from the produce, ways of sharing the produce and so on. The section on gold would have various computational techniques related to estimation of quality of gold, its price and computations related to various combinations in the making of per unit of gold. Gold was also unit of money and this section would also have various types of computations related to transactions in money in goods and labour. The section on grains, paddy and rice dealt with techniques to compute volumes of grain using different units, conversion techniques, profit and loss etc. The section on solid stones would deal with various problems related to measures of slicing solid bodies like rocks into pillars and of similar kind. There is also a section on water that almost exclusively deals with distribution of irrigation water for agriculture from tanks and canals. In the last section there would usually be various problems that use different rules and techniques in the context of various situations that were both practical and immediate as well as the fantastic and the recreational.

There were other texts like the *kaṇita nūl* which belong to this genre. The author of this text states that the work was not an original treatise but adapted - “as I went through the mathematical treatises composed by our forefathers, I wondered how they were able to create such good models. Today I take courage to write a treatise myself. This is like an ornamental doll in a tower imagining that it is the one which supports the tower" (Subramanian. P & Kamesvaran. K. S, 1999, p.27). This was composed in the year 1693 A.D and has six different sections on numbers, linear measures, cubic measures, weight, time and common problems.

While different texts had different ways of putting together such compilations of rules or techniques, they were generic in their orientation to the local and the immediate world of transactions in land, labour and produce, in relation to the objects of computation as well as the types of techniques. The context of the rules point to a distinct functionality in their objective, a system of useful knowledge, anthologized and put together for the purpose of record and hence for passing it on. They were drawn from contexts of everyday life and and employ a poetics, which set rules of literary composition. Likewise these texts attempt to explain, adduce the principles of computation gleaned from practical situations and suggest ways in which we may deploy these principles in practice. However they were not meant to train specialist or professional knowledge as in the case of a craftsman or a smith or an artisan, as participation in such trades meant training oneself on the job, especially in a social order where acquisition and transmission of specialist knowledge was restricted to spheres marked by kinship and community relationships often ritually sanctioned, as in the case of Brahminical learning. In case of this genre, there were no social or ritual sanctions that excluded people from participation explicitly. While they would not preclude anyone from learning the kind of mathematics as compiled together in these texts, the very act of anthologizing also involved a political process where certain classes remained outside the purview of circulation of such written mode of transmission of knowledge. For example, in case of distribution of irrigation water for agricultural lands, the traditional institution of the *talaiyari*, in the local village administration, a lower caste untouchable person was responsible for the actual task. In all probability he was never trained in this mode of knowledge transmission to deal with water distribution in practice, through the use of these texts. However his knowledge and labour constituted an object for training in practical computation in the circulation of which (in the written/institutional mode) he cannot partake. Training in such practical computations on the other hand would definitely prepare a person of other communities for an occupation or a range of occupations. Given the social context for the circulation of this system of knowledge, I shall briefly dwell on some of their characteristics in relation to the ethos of their transmission.

Modes of computation were oral in a culture where writing was only adjunct or an aid in practices centered on recollective memory (Carruthers. M, 2008). This probably meant in the context of transmission that the execution of a procedure in problem solving involved another person, who would be able to follow the procedure or at least find his participation in the communication useful. Computation was simultaneous communication. But to get there, prior training in the memory of various tables was important, through the learning of the *eṇcuvaṭi* or table books, taught in the *tiṇṇai* schools. These *tiṇṇai* or the veranda schools were institutions of indigenous elementary learning for the upper and the intermediate caste groups where children were taught letters and numbers in the mode of recollective memory (Dharampal, 1983). Therefore, associating a procedure, in a problem solving situation, backed up by recollective memory-training via the tables, was an ideal capability that a practitioner of this mathematics expected to achieve. Memory was a virtue, and when combined with identifying techniques for problem solving involving various situations, it constituted a skill (Senthil Babu, 2007).

This skill had to be nurtured and developed. It occurs form the nature of mathematics present in these texts that the society valued such skills and rendered the process of acquiring these skills a dignity. But through the process of acquisition and after, such skill had to be expressed, not to be possessed. Not personal skills, but public - meant for performance. Imbued in the ethos of functionality, *kaṇakkatikāram* while constructing a public, also invited it to make themselves 'clever', 'prudent', to face challenges in daily life and to remain unfazed in front of experts. What is striking in this tradition, is a different kind of humanism at work, as evident in the texts and in its mnemonic verses. There are at times, efforts to hard-sell mathematics, but coupled with a persuasive tone, as if to convince its public that learning mathematics was desirable and possible. But there were also normative ideals related to the mastering of computational procedures.

For example, in the text, *āstāṉa kōlākalam*, the author says, while it is a common occurrence in society that people forget their mathematical tables the moment they leave school, it is also equally common that there are people who are 'intelligent' and feel comfortable in public when confronted by 'an assembly of a hundred mathematicians'. Public display of proficiency in computations, was acknowledged as a legitimate and a worthy pursuit. So, both the 'computationally weak' and the 'intelligent' can benefit from his work, but the only difference would be that the 'intelligent' one would acquire the fragrance of a golden flower! (Sarma. S, 1951, p.1). Simultaneous privileging of the 'proficient' – the skilled intellect, along with a concern towards the lay and the ordinary person, seemed to be an invitation, a gesture to everyone to find their use in this work. In another version of Kari Nayanar's *kaṇakkatikāram*, there is a loud proclamation on the virtuosity for the computationally proficient. The particular verse in this edition says that the '*vattiar*', the teacher who masters the mathematical treatises from Kari Nayanar's *kaṇakkatikāram* to that of *āstāṉa kōlākalam* could be compared to an axe, which is so sharp like the *vajra ayutam*, good enough to split open the torso. The sharpness of the intellect of the teacher is metaphorically alluded to the mythical weapon, *vajra ayutam* (*kaṇakkatikāram*, 1832, p. 4).

Mathematics also provided with exclusive qualities, in relation to its public. The author of the text *kaṇ*ita nūl talks about certain virtues in a series of verses [Subramaniam. P & Kameswaran. K. S, p. 66].:

> "the world stands merged with the science of numerals. The study of numerals is like an attempt to scale the m*ēru* mountain while the study of letters is like climbing a post standing on quicksand. There are two kinds of knowledge – that of the numerals and of the letters. There are three kinds of treatises – (*mutal, vaḻi, cārpu*) original, derivative and adoptive. There are four effects of learning – ethics, wealth, pleasure and salvation. There are six kinds of defects associated with mathematical practice – (*ku*ṉṟal) underestimation; (*k*ūṭṭal) overestimation; (*kūṭṭiya tokai kāṭṭal*) wrong consolidation, (*māṟukoḷak kūṭṭal*) self-contradiction; (*vaḻut tokaip puṇarttal*) defective usage and (*mayaṅka vaittal*) creating confusion or dilemma. There are seven kinds of virtues associated with mathematical practice – refusal to concur immediately; accepting others' proposition and clear mistakes in them; stand by one's own proposition; choosing the right view in a situation of differing opinions; ability to point out others' mistakes; and the ability to differentiate between one's work with that of the others. There are eight devices of understanding – addition, subtraction, multiplication, division, comprehension, identification of unique distinction, ability to differentiate and to explain or articulate. Finally there are three kinds of students – the first rate, second rate and the third. The first rate is like the mythical bird called the *acuṇam*, which would fall dead the moment it hears a jarring discordant note in music; the second rate is likened to that of an eagle, which surveys its prey before picking on it and the third rate is the one like a hen, which keeps picking on the garbage till it finally manages to get something useful" [translation mine].

Engagement with the world of numbers was considered a worldly enterprise, more privileged than engagement with letters. Learning mathematics was like scaling the mythical mountain, *mēru* which metaphorically would mean that learning math was tough. It takes effort but nevertheless blessed with direction and reliable since the Gods reside in the *mēru* mountain. The learning of letters is like a post that seems conquerable, yet standing on quicksand, which could easily prove to be slippery and uncertain. There are two kinds of pitfalls in the acquisition of this skill: overestimation, underestimation and wrong consolidation pertain to the realm of the quantitative (that are of common occurrence in arithmetic operations) while self-contradiction, defective usage and creating confusion fall in the realm of the qualitative which are indicative of the need for clarity in approach, in thought and in application of procedure. Further there is yet another distinction that is established which is significant in terms of espousing a critical apparatus for this mode of arithmetic practice – between attitude and judgment. While refusal to concur, accept, clear mistakes in others' propositions and to stand by one's own proposition all clearly pertain to the virtue of having the right kind of attitude, virtues like choosing the right view, ability to point out other's mistakes and the ability to differentiate between one's own work with that of others all pertain to the virtue of judgment in practice. The distinction between attitude and judgment in the practice of this skill with clear demands of rationality and consistency along with clarity and discernment provides us with a set of highly critical and reflexive set of virtues and ideals that a practitioner of this mode of mathematics would yearn for, or in other words a system of potential virtues and ideals that *kaṇakkatikāram* held for its public. In this particular case, the teacher or the preceptor in a pedagogic context of transmission of this variety of mathematical practice then would become a highly disinterested figure – some one who can not only set such norms and ideals but also is capable of more. The ideal computational proficient could decide on the nature of the normative ideals also meant that the learner or the student had a lot to aspire for. Therefore of the three types of students categorized as above, the first one is so fine and superior that he or she cannot bear discordance, possessed with a sense of proportion and harmony – almost that of a philosopher or an aesthetician. The second type of student could be highly discerning like an eagle with a sense of practical intelligence with an ability to judge what he or she wants. The third student could be any of us or all of us who would take all chances with this tradition through sheer perseverance.

The professional virtuosity of the teacher or the preceptor and the acknowledged possibilities of any learner or participant in this tradition to be superior, intelligent or be persevering could only apparently point to a hierarchy of virtues. But when taken along with the system of arithmetic practice in question, it could be read as different options available for anyone to partake in this practice, because ultimately the goals anyway are ethics, wealth, pleasure and salvation. Such humanist ethos in the realm of seeking knowledge also shows us how this knowledge could transcend the immediate and reach out for something more – a better aesthetique or a much higher spiritual quest like scaling the '*mēru*'. In this mode *kaṇakkatikāram* then possibly was not a free knowledge for all but strongly connotes the advantages of sophisticated forms of computation, yet grounded in the local and the functional while emphasizing the affective and aesthetics of the knowledge practice. This could be recognized and discerned in almost all the regional traditions of mathematics in the country. This could also help us in interrogating the historiographical and political processes by which a canonical 'Indian' tradition of mathematics was constructed at several moments in our past. This would also help us re-look at some of the categories used in the construction of such a canonical tradition to understand why and how the functional and the practical have always been made to appear as if they lack a critical and reflexive apparatus for themselves – a theory of practice, which would render a sense of dignity while retaining their strongly humanist core.

Mathematics, the British public and colonial education

Now, we move on to a particular moment in the early nineteenth century colonial encounter. The *kaṇakkatikāram* tradition's institutional training ground were the *tiṇṇai* schools, which flourished in the eighteenth and the nineteenth centuries. Learning mathematics was an integral part of these schools, to the extent that it defined the pedagogic and organizational mode of the institution. The mode of learning under recollective memory and the monitorial system together defined the nature of these elementary learning institutions that were far and widespread in the Tamil regions, as well as in all parts of India (Dharampal, 1983; Basu. A, 1982).

During the end of the eighteenth century, Andrew Bell, a Scotsman and the Company chaplain of the Egmore Military Male Asylum in Madras, on one of his morning rides, witnessed the working of the *tiṇṇai* school and was clearly impressed. He reworked the *tiṇṇai* pedagogy and its rhythm into a Christian system of education. Internally, the memory mode of learning in the *tiṇṇai* school, using mutual instruction was reconstructed with respect to reading, writing and arithmetic, the three R's, as then conceptualized in England as constituting elementary education. Bell published his 'discovery' and called it the Madras system in 1797 giving rise to a story of the evolution of a pedagogic system, which traveled from India, became one of the primary means to popularize elementary education in England and came back to India, all along going through continuous attempts at modification and improvement (Tschurenev. J, 2008). The Tamil *tiṇṇai* school's regime of pedagogy in recollective memory enmeshed with principles of Scottish political economy, imbibed by Bell, who reorganized the monitorial system to resemble idealized forms of factory in such a way that the principles in manufacture and in schools would be the same. Bentham's utilitarian ideology, which had its role in the making of British colonial policy in early nineteenth century, praised Bell's invention as "the most useful of all products of inventive genius, printing excepted, that this globe has ever witnessed and that it may be applied to the highest branches of useful learning". For its 'profit maximization and expense minimization', the division of labour in the monitorial principle was rather revealing to the utilitarian ideologue. For Bell himself, the monitorial system was "like the steam engine or the spinning machinery, it diminishes labour and multiplies work, but in a degree which does not admit of the same limits and scarcely of the same calculations, as they do" (cited in Schaffer. S, 2010). As Schaffer argues, this was a machine utopia of a specific form, simultaneously showroom and classroom. Each school was to be divided into sets of classes, with more junior inmates subject to more advanced pupils; each stage was meticulously registered; each lesson divided into brief segments; under the "place-capturing principle" each member of each class moved around the tightly disciplined space of the class room; and the whole was under the surveillance of an inspector, "whose scrutinizing eye must pervade the whole machine" under a "never-ceasing vigilance". Samuel Coleridge, considered Bell's monitorial system as a 'vast moral steam engine' and said that it must be adopted in free motion through out the British empire (Schaffer. S, 2010, p.14-16). The ethos of *tiṇṇai* learning that sustained the *kaṇakkatikāram* tradition transformed and situated into a different system of virtues in England. Blessed by the Episcopal authority of the Church of England, it was brought by the British missionaries back to India, as a crucial element of their evangelical work in the colony.

Around the same time, the nature and purpose of a liberal education system in British higher education was being evolved and debated. In particular, for the British mathematical community in the early 19th century, it was rather important to engage with this debate and to argue before the British public, as to what mathematics could offer them. William Whewell, scholar, mathematician and influential public figure in England, argued that mathematics was all about the cultivation of the mind, in contrast to the exercising of the body in the popular education movement of Bell's system. The objective of a liberal education was 'the whole mental development of man' and mathematics was best suited for that purpose. There were two opposing views about mathematics in contemporary England. One held,

> "it is the most admirable mental discipline; that it generates habits of reasoning, of continuous and severe attention, of constant reference to fundamental principles. On the other side, it is asserted that mathematical habits of thought unfit a man for the business of life – make his mind captious, disputatious, over subtle, over rigid – that a person inured to mathematical reasoning alone, reasons ill on other subjects, seeks in them a kind and degree of proof which does not belong to them, becomes insensible to moral evidence, and loses those finer perceptions of fitness and beauty, in which propriety of action and delicacy of taste must have their origin" (Whewell. W, 1836).

But for Whewell, mathematics was an example and an exercise in exact reasoning. The whole purpose of education was to trace securely and readily the necessary consequences of assumed principles:

> “Men's minds are full of convictions which they cannot justify by connected reasoning, however reasonable they are. Nothing is more common than to hear persons urge very foolish arguments in support of very just opinions and what has been said of women is often no less true of the sex which pretends to have the more logical kind of head – namely, that if they give their judgment only, they are not unlikely to be right, but if they add their reasons for it, those will most probably be wrong. There prevails very widely an obscurity or perplexity of thought which prevents men from seeing clearly the necessary connexion of their principles with their conclusions... therefore the task of liberal education is to make his speculative inferences coincide with his practical convictions”.

To cultivate the mind, to exercise and train the reasoning faculty is best done by mathematics, and not even by Logic. While logic is reasoning by rule, mathematics is reasoning by practice. Reasoning is a practical process and must be taught by practice, in the same manner as fencing and riding, or any other practical art. The student should be able to

> “conduct his train of deduction securely, yet without effort, just as in the riding school, the object is that the learner should proceed firmly and easily upon his stead... the horseman, tries to obtain a good seat rather than to describe one, and rather avoids falling than considers in how many ways he may fall. To cultivate logic appears to resemble learning horsemanship by book”.

Habitual exercise, continuity and concentration of thought, and the quick sense of demonstration were virtues for a strong British character and mathematics was the ideal subject which can provide these. Arguing for reforms in British university system of teaching mathematics, and enrolling the support of the British public in the process, Whewell argued that products of such a reformed learning process would make the best professionals, in particular, the best lawyers and law makers. Deduction, steadiness and perseverance through the practice of reasoning and to proceed from the first principles towards the singular truth and attain firm conviction, along with ability to see fallacies and not to yield to them, was the system of virtues that British math was offering its public in the name of liberal education in early 19th century Britain. Such virtues were not very different from that of the normative ideals of the kaṇakkatikāram tradition as discussed earlier, pointing to ways of a shared ethos of learning mathematics when conceived as a system of practice, for anyone to participate in. However how exactly such ethos materialized in the mathematical practices of these two different cultures requires a different mode of historical inquiry.

Both Bell and Whewell, conspicuously played their part in the way modern mathematics was localized in colonial India. Bell's 'moral steam engine' was the dominant system of missionary education in their Indian schools, where they did talk about 'sympathy and emulation' as Christian virtues, which were best cultivated among the native children through the monitorial system. The Madras system of education was back in Madras, and in rest of India but with a different mould of virtuosity. This process of localization interestingly involved a contention between the new ethos of the Madras system of Bell and the Madras system of the tiṇṇai, as it were. The history of nineteenth century elementary education in the Tamil speaking region could be rewritten as a history of this process of negotiation between the contending ideals of pedagogy in the historical context of the making of a colonial revenue administration. Through this process, a system of arithmetic teaching was put together by the missionaries in south India by the mid nineteenth century whose salient features were: a) plan of mutual instruction with monitors guiding the students b) memory and its practice central in reading and arithmetic, with loud recital, simultaneous vocalization and visualization while writing c) memorization begins with the writing down of figures in sand tables d) centrality to tables, with the difference being (in relation to tiṇṇai) that the four operations of arithmetic taught in relation to each other by simultaneous construction of addition and subtraction tables, and multiplication and division tables e) memorization proceeds along with the construction of tables f) memory tested step by step by the monitor during the construction of the table and while associating with operations g) the actual operations however now had to be worked out on slate, and by using columns, making the slate, the central device h) Keys, or guidebooks to the monitors became essential I) the general plan of arithmetic teaching became standardized as: 1. Combination of figures 2. Addition 3. Compound Addition 4. Subtraction 5. Compound Subtraction 6. Multiplication 7. Compound Multiplication 8. Division 9. Compound Division 10. Reduction 11. Rule of Three 12. Practice j) emulation, rewards, steadiness of application become the normative values for students to imbibe (Senthil Babu. D., 2011).

The rhetoric of liberal education, guided by the utilitarians in the colonial administration in the first half of the nineteenth century, had to come up with a scheme of educating the natives, as part of their 'civilizing mission'. The early company interventions in education in combination with the missionary efforts initiated a long and complex process of instituting a colonial educational machinery. The defining features of this process could be identified with certain basic changes like the centrality of the textbooks, organized classroom instruction, changes in the modes of evaluation from the local-public into one centered on written examinations, the coming in of a centralized authority to decide on matters of curriculum and evaluation thereby creating a new connection between education and employment based on ideas of merit and achievement. The ways in which such changes conditioned the teaching and learning of arithmetic is another story altogether. For the purpose of our discussion here, suffice here to mention that the learning of arithmetic went through two significant changes: through the early colonial interventions intended to liberate native education from the rote memory culture of the indigenous tradition, ironically, the learning of arithmetic became steeped further in mechanical memory and second, problem solving now became very procedural and to follow rules to get to solutions with diligence came to acquire a central place in order to score well in examinations. Such rules were to be treated as the rules of God [Naicker. P. R, 1825].This was not very different from what was happening in England around the same time, as scholars like August De Morgan were already lamenting about (Phillips. C, 2005).

Mechanical or rote memory would continue to haunt the teaching and learning of mathematics. The functionality of the indigenous tradition and the skills that it assured were evaluated differently. Dislodging them became the primary objectives of the entire colonial education apparatus for most of the nineteenth century, in the process collapsing the virtues associated with the mythical bird, the eagle and the hen. Young learners were all now rule following subjects of mathematics. It was not cleverness and prudence that would be the guiding virtues anymore. They had to be qualified members of a recruitable public for the needs of a colonial administration in the making. Of course, this necessity would not constitute as yet another version of functionality for the colonial empire. How did this ambiguity pervaded the making of a modern system of teaching and learning of mathematics in the country awaits scholarly attention. This would offer certain insights to contemporary challenges in mathematics education to rescue the learning of mathematics from the rule bound problem solving mode and return it to the dense demands of everyday life of computations based on local practices in every field, allowing for the joy of mathematics as play, as performance?

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The Effect of Achievement, Gender and Class Room Context on School Students' Mathematical Beliefs

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The influences of achievement, gender and classroom context on students' mathematical beliefs were analyzed. In this present study the researchers adopt the descriptive survey method. All the students studying in class IX and X in secondary schools situated in Karbi Anglong district of Assam constitutes the population of the study. A sample of one thousand two hundred forty (1240) students were selected from 48 secondary and higher secondary schools of Karbi Anglong for the study. A research instrument was developed by the researchers on the basis of modified Fennema Sherman Mathematics Attitude Scale to collect data for the study. The study reveals that there exists significant differences in attitude towards mathematics, between male-female students, rural-urban school students and public-private school students. Researchers find a strong positive correlation between students' attitude towards Mathematics and their academic achievements in Mathematics.

Introduction

There has been an increased interest among the researchers to study the role of mathematical beliefs in the learning of mathematics (Schuck & Grootenboer, 2004) and Leder,2006). Grootenboer (2003) found that positive mathematical beliefs are significantly related to increased mathematical achievements. Many researches has been conducted on the important roles of beliefs in teaching and learning of mathematics. Thompson (1992), Rechardson (1996) and Phillip (2007) are some of such researchers.

In the educational literatures we cannot find a common generalized definition of belief. The distinction between belief, conception and knowledge is not clear (Pehkonen, E. & Törner, G,1999). According to McLead and McLead (2002) the concept of belief is a complex one. Beliefs are components of a recently developed social, psychological construct (Goldin, Epstein and Schorr, 2007).According to Green (1971) beliefs never occur as a single thing, they appear in bundles (Maass, Schlöglmann, 2009). Goldin (2003) found that beliefs are 'interwoven' into systems with other beliefs. Beliefs can be considered as "aggregates of mental states." (Goldin,Rosken,Torner,2009). Beliefs of an individual is a complex mixture of various possible perceptions, characteristics, philosophies, suppositions and ideological states of that individual. The nature of relationship between beliefs and behaviour is important. Some researcher says that beliefs influence behaviours and on the other hand some argue vice-versa. Context is another important factor for the growth of positive beliefs towards mathematics. Hayles (1992) argued that context is useful in the development of an individual's beliefs.

Attitudes of an individual are closely related to the beliefs of that individual. Martino and Zan (2001) said in their research works "In mathematics education the words 'beliefs' and 'attitudes' are often used as synonyms." According to Mc Leod (1992) "In the literature it is difficult to separate research on attitudes from research on beliefs". White, Way, Perry and Southwell (2006) argued "For each belief an individual would have a corresponding attitude". In mathematical language we can say that there exists a one to one correspondence between attitudes and beliefs. Considering these views the researchers are using a research instrument developed on the basis of modified *Fennema Sherman Mathematics Attitude Scale* to collect data for the study.

Gender differences and mathematical beliefs is another area of research in recent times . In developed countries the gap between gender differences and mathematics achievements in secondary schools is gradually narrowing (Fennema and Hart 1994, Beatan et.al. 1996). But there exists clear gender differences regarding mathematical beliefs (Leder et al.,1996). Boys believe that mathematics is a male dominant area. On the other hand girls believe that mathematics is gender neutral (Forst, Hyde & Fennema ,1994). Leder (1993), Hannula (1997), found in their research that boys have higher self confidence than girls in the area of mathematics. Young explored the attitude towards mathematics and found that boys like mathematics more than girls.

Regarding the secondary schools of Karbi Anglong district of Assam, there exists significant differences between the mathematics achievements of male and female students (Ahmed and Bora, 2011). The researchers found that with students from low income families there is a big difference (12%) in mathematics achievements between male and female students of secondary schools of Karbi Anglong. In a recent study Ahmed and Bora

(2011) found that the mean scores of mathematics teachers' positive attitude towards mathematics is only 40.25, which indicates that in Karbi Anglong district of Assam mathematics teachers of secondary schools have less positive attitudes towards mathematics. The researchers also established the fact that school environment has great impact on building of students' belief towards teaching mathematics and on performances of school learners.

Hypotheses

The following null hypotheses are constructed for the study

H1: There is no significant relationship between achievement and students attitude towards mathematics.

H2: There is no significant relationship between gender and students attitude towards mathematics.

H3: There is no significant relationship between school environment (rural and urban) and students' attitude towards mathematics.

H4: There is no significant relationship between class volume and students' attitude towards mathematics.

Methodology

In this present study the researchers adopt the descriptive survey method. All the students studying in class IX and X in secondary schools situated in Karbi Anglong district of Assam constitutes the population of the study. A sample of one thousand two hundred forty (1240) students was selected from 48 secondary and higher secondary schools of Karbi Anglong for the study. A research instrument has been developed by the researchers on the basis of modified Fennema Sherman Mathematics Attitude Scale to collect data for the study.The study investigates the difference in attitudes of school students towards Mathematics by gender, proprietorship of school and environment of school.

Urban	Rural
24	24

Table 1. Distribution of schools

Gender		Class Volume		School Environment	
Male	Female	<50	>50	Urban	Rural
700	540	620	620	620	620

Table 2. Distribution of respondents (Students)

Research Instrument

To examine the effect of achievement, gender and classroom context on attitude towards mathematics the researchers developed a research instrument. *Students' Attitude Towards Mathematics Scale* (SATMS). This scale was developed on the basis of Fennema Sherman Mathematics Attitude Scale. SATMS consists of two sections. Name, gender, community, category of the student were asked in the section A. The name of the school was also included in that section. Section B consists of 30 questions, 15 of them were positively worded and 15 of them are negatively worded. The SATMS was designed to investigate the underlying dimensions of attitudes towards mathematics. Items were constructed to assess confidence, anxiety , value, enjoyment, motivation and parent-teacher expections. In each dimension 6 questions are asked. Students are expected to answer the questions by expressing their level of agreement as five point scale of strongly Agree(A), Agree(B), Neutral(C), Disagree(D),Strongly Disagree(E). A pilot survey was done with SATMS on 30 students in Diphu area. Cronbach Alfa coefficient was computed to determine the reliability and the value obtained was 0.71. SATMS is prepared having five levels of expressions for each item. Weights assigned to each level are as the following table.

Level of Response	Scores	
	Positive items	Negative Items
Strongly Agree(A)	5	1
Agree(B)	4	2
Neutral(C)	3	3
Disagree(D)	2	4
Strongly Disagree(E)	1	5

Table 3. Weights assigned to different levels

For SATMS the possible score ranges from 30 to 150 .

Data Analysis and Interpretation:

Collected data are tabulated and Mean, standard deviation and t-test are applied to analyse data.

Sl No	Statistical Measure	Boys	Girls	<50	>50	Urban	Rural	Total
1	Total Score	1250	651	1725	1443	1195	706	1901
2	Mean	50.19	23.76	44.3	40.09	46.5	29.4	40.25
3	S.D.	12.34	8.25	10.2	11.4	16.08	13	14.63
4	No of schools	-	-	24	24	24	24	48

Table 4. Students' Attitude Responses.

Sl No	Statistical Measure	Boy	Girl	<50	>50	Urban	Rural	Total
1	Student Appeared	620	620	620	620	620	620	1240
2	Student Passed	409	211	321	299	381	145	526
3	Passed %	65.97	34.03	51.78	48.22	61.45	23.38	42.41
4	Mean	17.04	8.79	13.38	12.46	15.88	6.04	11
5	S.D.	5.3	2.5	3.1	3.9	3.76	4.50	6.82

Table 5. Students' Academic Achievements in mathematics

The mean score of students' attitude towards mathematics is 51.25 out of 150. This indicates that secondary school students studying in Karbi Anglong district of Assam posses only 34.17% positive attitude towards mathematics which is very low. Male student's attitude responses $(\bar{x}=50.19, \sigma=15.02)$ are higher than that of female students $(\bar{x}=23.76, \sigma=10.34)$. Attitude Responses of students are higher in urban areas $(\bar{x}=46.5, \sigma=16.08)$ than in rural areas $(\bar{x}=29.4, \sigma=13)$. Regarding class volume, there is no significant difference between class having less than 50 students $(\bar{x}=37.25, \sigma=9.23)$ and classes having more than 50 students $(\bar{x}=35.3, \sigma=10.15)$. The calculated t- value for students' mathematics achievement and students' attitude towards mathematics is 4.78 which is much higher than the tabulated value 1.96 .Therefore the null hypothesis H1 is rejected i.e there exist a significant relationship between achievement and students attitude towards mathematics. The calculated t- value for gender and students' attitude towards mathematics is 4.22 which is much higher than the tabulated value 2.069 .Therefore the null hypothesis H2 is rejected i.e there exist significant relationship between gender and students attitude towards mathematics. The calculated t- value for school environment (Rural or Urban) and students' attitude towards mathematics is 4.22 which is much higher than the tabulated value 1.96. Therefore the null hypothesis H3 is rejected i.e there exist significant relationship between school environment (rural and urban) and students' attitude towards mathematics. The calculated t-value for class volume and students' attitude towards mathematics is 1.85 which is smaller than the tabulated value 1.96. Therefore, the null hypothesis H4 may be rejected i.e there is no significant relationship between class volume and students' attitude towards mathematics.

Discussion and Conclusion:

In this study the researcher sought to investigate the relationship between academic achievements of students in mathematics and belief on mathematics i.e attitude of students' towards mathematics; relationship between gender and attitude of students' towards mathematics; relationship between classroom context (school environment and class volume) and attitude of students' towards mathematics. Results from the study show that mean score of students' belief or attitude towards Mathematics is only 40.25 out of maximum score 150 , which indicates that students have low positive attitude towards Mathematics. Achievements in mathematics and gender have good effect on students attitude towards the subject. School environment has also significant impact on belief building but class volume has no contribution on students' belief regarding mathematics.

Further study may be carried out to find out the reasons of students' low positive attitude towards mathematics in this ST dominated region of India. The present study reveals that there exist a strong corelation between students' attitude towards mathematics and students' academic achievements in mathematics. Moreover, this study reveals that school environment has a great effect on students' attitude towards mathematics and their performances in mathematics.

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Choice of a Science Major: Fashioning a Model for Female Undergraduates in India

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The study aimed to prepare a model linking independent variables viz., science major, year of study, reason for choice of major and hobby with dependent variables viz., achievement motivation, career/ family values and locus of control of female undergraduates in India. Techniques of area and stratified random sampling were followed to select a sample of 180 women undergraduates belonging to 5 districts of West Bengal (a state in India). Among them 60 each were majoring in Physics, Chemistry and Zoology. Besides, 60 each were studying in 1st, 2nd and 3rd year of college. A general information schedule and 3 psychological tests (standardized in India) were administrated to the students to collect data. MANOVA revealed : i) groups formed on the basis of the independent variables differed significantly with respect to student-attributes; and ii) reason for choice of major significantly influenced student achievement motivation .

Introduction

Research literature is replete with studies on influence of student-attributes on course-choice. But studies on impacts of choice of majors on student-attributes are scarce. Noteworthy models on impacts of college (Astin, 1993; Pascarella and Terenzini, 1991) are set in the West. These are of limited value in the Indian milieu. But similar models are yet to be developed in India hence the need for the present study. Indian women have to overcome many obstacles to pursue tertiary education in science. So a model on effects of choice of a particular science on their psychological attributes promises to be illuminating.

Existing Western models (Astin, 1993; Pascarella and Terenzini, 1991) reveal an array of interacting variables. However, selection of variables for the proposed model is guided by survey of research keeping Indian women's perspective in mind. Type of science major studied would be an independent variable. This is because science majors vary in their perceived suitability for women. Physics is regarded abstract hence masculine (Hazari and Potvin, 2005). Chemistry seems less masculine (Hofstein et al., 1977). Biology is rated feminine (Abouchedid and Nasser, 2000) as it agrees with the stereotype of females as nurturers (Baker and Leary, 1995). So choice of a science may have psychosocial repercussions. Even in the West women's achievement motivation has been found to vary with the major they study (Kae Won Sid and Lindgren, 1981). Females in non-traditional sciences tend to cite external career-barriers more than those in traditional ones (Silcox and Cummings, 1999). Besides, studying natural science reportedly lowered pupils' family values (Mitchell et al., 2008). In the Indian patrifocal society women expectedly suffer conflict between career and family values. It reduces their achievement motivation (Bhargava, 1985; Gupta and Sharma, 2002). Such conflicts are greater for "masculine" subjects. Not only science major per se but reason for discipline-choice would be an independent variable since for most Indian women, the family selects the discipline (Chanana, 2004). So impact of science major-choice may depend on whether it was volitional or imposed. Women who can / do not exercise autonomous discipline-choice are said to manifest external locus of control (Marecek and Frasch, 1977). Autonomous discipline-choice, interest and having relevant hobbies promote achievement motivation (Baker and Leary, 1995; Kahle and Lakes, 1983). So type of hobbies one has may also be an independent variable. This is especially because females' lack of science-hobbies has been found to hinder their engagement with science (Kahle and Lakes, 1983). In India gendered socialization usually bars females from developing science-hobbies. Year of study (e.g. freshman; senior) determines the length of time a particular major was studied and consequently it's impact. So it is also included as an independent variable. By itself it has been found to influence locus of control of women in college (Howard, 1996) but not students' reasons for discipline-choice (Wilson et al., 2006). This survey of research also helped select dependent variables of the proposed model viz., achievement motivation, career /family values and locus of control. These were found to be influenced by the chosen independent variables and were relevant for Indian college women.

Aim of the Study

The investigation intends to prepare and test a model on the influences of science major, year of study, reason for choice of major and hobby on Indian college women's psychological attributes viz., achievement motivation, career value, family value and locus of control (powerful others; chance; individual).

Research Study

Operational Definitions of Dependent Variables

- Achievement motivation: A disposition to strive for success in competition with others with some standard of excellence set by the individual (Deo and Mohan, 2011).
- Career value: Attitudes towards paid work, professional interests and motivation to work efficiently (Tanwar and Singh, 1988).
- Family value: Attitudes towards marriage, children, other family members and interest in home management (Tanwar and Singh, 1988).
- Locus of control: Belief about one's outcomes being controlled by internal / external factors (Vohra, 1992). It has the following facets:-
    1. Powerful others: Belief about one's outcomes being controlled by powerful people (Vohra, 1992).
    2. Chance control: Belief about one's outcomes being controlled by random events (Vohra, 1992).
    3. Individual control: Belief about one's outcomes being controlled by oneself (Vohra, 1992).

Tools

1. General Information Schedule: Prepared by the author to gather identifying and background information from respondents. Chief reason for major-choice and most favoured hobby as indicated by each respondent were considered for analysis in the present study.
2. Standardized tools to assess the psychological attributes are as follows:-
3. Achievement Motivation Scale (Deo and Mohan, 2011): Consists of 50 statements to be responded to on a five-point scale. Items cover academic motivation, need for achievement, achievement anxiety etc. Can be administered to persons aged at least 13.
4. Career and Family Values Scale (Tanwar and Singh, 1988): Includes 40 statements to be responded to on a five-point scale. 20 items each cover attitudes towards professional and family lives of women. Used with female undergraduates.
5. Levenson's Scale for Locus of control, Indian Adaptation (Vohra, 1992): Comprises 24 statements regarding perceived control over personal outcomes. The statements can be responded to on a five-point scale. The tool yields 3 scores - one each for powerful others, chance and individual control. Suitable for use with youth and adults.

Sample Selection

Area sampling was used to randomly select 15 colleges (offering science majors) located in 5 districts of West Bengal (a state in India) viz., Kolkata, North 24 Parganas, South 24 Parganas, Howrah and Hooghly. Then a stratified random sample was drawn. Strata were based on science major and year of study. Equal numbers of female students (aged 19-22 years) of Physics, Chemistry and Zoology honours (major) course were selected randomly from each district. Equal representation of students of 1^{st}, 2^{nd} and 3^{rd} year of study was ensured through random sampling. The final sample comprised 180 female undergraduates – 60 each studying Physics (Honours), Chemistry (Honours) and Zoology (Honours). Across majors there were 60 women each studying in 1^{st}, 2^{nd} and 3^{rd} year.

Data Collection

Tools were administered to students in groups of about 20 individuals each at a time. Venues of data collection were colleges. Each session of data collection spanned about 1½ hours.

Statistical Analyses

Multivariate Analysis of Variance (MANOVA) with Full Factorial Design was conducted. Type IV sum of squares were computed as the design was unbalanced with some factor combinations having empty cells. SPSS 16 was used.

Results and Discussion

Initially descriptive statistics were calculated. Skewness and kurtosis values for dependent variables were within acceptable limits of ±1. Results of MANOVA are presented in Table -1. Factor combinations having empty cells and three-factor combinations with non-significant F-values have been deleted from Table 1. This was done for the sake of brevity.

Source of Variation	Dependent Variable	Sum of squares	df	Mean Square	F
Corrected Model	Ach Moti	26163.658 [a]	93	281.330	1.935**
	Career Value	7395.792 [b]	93	79.525	1.992**
	Family Value	23258.362 [c]	93	250.090	1.515*
	Powerful Others	3011.420 [d]	93	32.381	1.559*
	Chance	3372.498 [e]	93	36.263	1.395
	Individual	2074.017 [f]	93	22.301	1.475*
Intercept	Ach Moti	2519158.722	1	2519158.722	1.733E4**
	Career Value	887934.550	1	887934.550	2.224E4**
	Family Value	393580.076	1	393580.076	2.384E3*
	Powerful Others	54733.855	1	54733.855	2.635E3*
	Chance	73384.515	1	73384.515	2.824E3*
	Individual	117843.162	1	117843.162	7.795E3**
Major	Ach Moti	461.539	2	230.770	1.587
	Career Value	343.121	2	171.561	4.298
	Family Value	284.948	2	142.474	0.863
	Powerful Others	199.721	2	99.861	4.807
	Chance	11.441	2	5.721	0.220
	Individual	96.004	2	48.002	3.175
Year of Study	Ach Moti	262.132	2	131.066	0.902
	Career Value	225.067	2	112.533	2.819
	Family Value	313.922	2	156.961	0.951
	Powerful Others	106.030	2	53.015	2.552
	Chance	87.213	2	43.606	1.678
	Individual	11.206	2	5.603	0.371
Reason for choice of major	Ach Moti	6586.550	15	439.103	3.021**
	Career Value	371.382	15	24.759	0.620
	Family Value	2113.102	15	140.873	0.853
	Powerful Others	160.185	15	10.679	0.514
	Chance	456.580	15	30.439	1.171
	Individual	272.037	15	18.136	1.200
Hobby	Ach Moti	1581.914	11	143.810	0.989
	Career Value	951.720	11	86.520	2.167
	Family Value	4206.660	11	382.424	2.316
	Powerful Others	376.659	11	34.242	1.648
	Chance	460.881	11	41.898	1.612
	Individual	256.823	11	23.348	1.544
Major * Year	Ach Moti	474.666	4	118.667	0.816
	Career Value	412.148	4	103.037	2.581
	Family Value	1178.021	4	294.505	1.784
	Powerful Others	162.019	4	40.505	1.950
	Chance	237.281	4	59.320	2.283
	Individual	40.922	4	10.231	0.677
Major * Reason	Ach Moti	1965.606	7	280.801	1.932
	Career Value	580.955	7	82.994	2.079
	Family Value	1327.866	7	189.695	1.149
	Powerful Others	178.459	7	25.494	1.227
	Chance	181.403	7	25.915	0.997
	Individual	89.312	7	12.759	0.844

Major * Hobby	Ach Moti	624.916	4	156.229	1.075
	Career Value	113.704	4	28.426	0.712
	Family Value	986.014	4	246.503	1.493
	Powerful Others	173.251	4	43.313	2.085
	Chance	276.756	4	69.189	2.663
	Individual	107.187	4	26.797	1.773
Year * Reason	Ach Moti	1624.245	7	232.035	1.596
	Career Value	207.528	7	29.647	0.743
	Family Value	558.178	7	79.740	0.483
	Powerful Others	79.351	7	11.336	0.546
	Chance	43.529	7	6.218	0.239
	Individual	141.039	7	20.148	1.333
Year * Hobby	Ach Moti	417.592	5	83.518	0.575
	Career Value	507.854	5	101.571	2.544
	Family Value	1079.500	5	215.900	1.308
	Powerful Others	111.160	5	22.232	1.070
	Chance	348.838	5	69.768	2.685
	Individual	11.034	5	2.207	0.146
Reason * Hobby	Ach Moti	1331.973	5	266.395	1.833
	Career Value	401.924	5	80.385	2.014
	Family Value	1223.551	5	244.710	1.482
	Powerful Others	42.098	5	8.420	0.405
	Chance	279.276	5	55.855	2.149
	Individual	158.121	5	31.624	2.092
Error	Ach Moti	12501.542	86	145.367	
	Career Value	3433.203	86	39.921	
	Family Value	14199.216	86	165.107	
	Powerful Others	1786.491	86	20.773	
	Chance	2234.814	86	25.986	
	Individual	1300.094	86	15.117	

a.R^2 = 0.677** (Adj. R^2 = 0.327 **); b. R^2 = 0.683** (Adj. R^2 = 0.340**); c. R^2 = 0.621** (Adj. R^2 = 0.211**); d. R^2 = 0.628** (Adj. R^2 = 0.225 **); e. R^2 = 0.601** (Adj. R^2 = 0.170*); f. R^2 = 0.615** (Adj. R^2 = 0.198**). *Ach Moti: Achievement Motivation* **p <.05; ** p<.01*

Table 1. Summarized results of MANOVA

Significant F-values for the corrected model (Table 1) show that women belonging to different majors, years of study and reporting different hobbies as well as reasons for choice of major vary significantly in their extents of achievement motivation, career / family values and beliefs in personal outcomes being controlled by powerful others as well as by oneself. Corrected model refers to the variance in the dependent variables which is accounted for by the independent variables without the intercept being taken into consideration. R^2 values beneath Table 1 are all significant. These report the proportion of variance in each attribute which can be accounted for by the independent variables. Even if adjusted values are considered, as much as 34% variance in career value can be accounted for by the independent variables. The corrected model is presenting variances in attributes sans the role of the intercept. The intercept refers to the point on the Y-axis where the regression line cuts it across. When F-values for the intercept (Table 1) are considered, groups based on independent variables are found to differ significantly in participants' attributes i.e., achievement motivation; career / family values; belief in personal outcomes being controlled by powerful others, chance and oneself. Besides, a small value of Wilk's Lambda i.e., .001 (F=9.536E3; Sig .000) had been obtained for the intercept. It also shows large difference (in means of attributes) between the groups being analysed. The results pertaining to the corrected model and the intercept indicate that independent variables included in the proposed model were found to collectively influence the dependent variables. These findings agree with those of Kae Won Sid and Lindgren (1981), Kahle and Lakes (1983), Marecek and Frasch (1977), Mitchell et al. (2008) and Silcox and Cummings (1999).

As for separate influences of the independent variables only respondents' stated reason for choice of major has been found to significantly influence their levels of achievement motivation (F=3.021** in Table 1). Reason -"I am interested in studying this subject" topped respondent-endorsements. It was cited as the chief reason by 103 women out of 180.This disagrees with findings that Indian women are socialized *not* to exercise their discipline-choice (Bhargava, 1985; Chanana, 2004). Women's empowerment in this respect seems to have grown with time. Roy's Largest Root for reason for choice of major is 0.809 (F=4.637; Sig. .000). It also highlights the importance of the factor-reason for choice of major. Roy's Largest Root for major is 0.273 (F=3.728; Sig. .003). It shows that individual-attributes differ to some extent with the type of science major they study. This agrees somewhat with findings of Kae Won Sid and Lindgren (1981), Mitchell et al. (2008) and Silcox and Cummings (1999).

Evidently the influence of major appears to be weaker than that of reason for choice of major. It is plausible that irrespective of the major it's effects on attributes may be strongly facilitating / detrimental depending largely on whether the woman chose it herself or it was imposed. Roy's Largest Root for hobby is 0.399 (F= 3.121; Sig. . 001) and that for reason for choice of major*hobby is 0.296 (F= 4.198; Sig. .001). These indicate that respondents' hobbies (whether by themselves or in interaction with respondents' reasons for choosing a particular science major) are also somewhat important. It is congruent with results of Kahle and Lakes (1983) that science-hobbies of women promote their involvement with science. In turn achievement motivation, career values and individual control over outcomes may be promoted by involvement with science. The kind of hobbies a woman has may make her choose a science major which is in tandem with these hobbies. So the interaction between hobby and reason for choice of major may influence the attributes. If women can/do not choose science majors which agree with their hobbies then their achievement motivation, career values and internal locus of control may be undermined.

Conclusion

It seems feasible to fashion a model linking independent variables - type of science major, reason for choice of major; hobby with dependent variables - achievement motivation; career/ family values; locus of control of female undergraduates in India. The model has been substantially supported by test-results. It helped gain insight into the dynamics surrounding women's science major choice in India and flag the factors which may hamper achievement motivation, career values and internal locus of control. However it appears from the results that year of study is not an important component of the model. This contradicts Western views (Astin, 1993; Howard, 1996; Pascarella and Terenzini, 1991). Whether it is justified to include year of study in a model based in India may be ascertained if this research is replicated with a larger sample. The finding that respondents' stated reason for their choice of a particular major has significant impact on their achievement motivation has important implications. This indicates that rather than the type of science major being studied, *the rationale behind the choice of the major exerts more powerful influence on achievement motivation of women undergraduates in India. It also underscores the need to ensure autonomous discipline-choice among Indian women so that their achievement motivation gets a boost.* The results have revealed the role of hobbies of the women in influencing their attributes. *It suggests that having hobbies congruent with the study of science or better still with their chosen science major may foster women's achievement motivation, career values and individual locus of control.*

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Drama-based Instruction of Geometry: A Teaching Experiment through the New Philosophy of Mathematics Perspective

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The present paper focuses on exploring the dynamics of Drama in Education Techniques in teaching Geometry inspired from new philosophies of mathematics. We describe a research didactical experiment regarding Drama-based instruction of the axiomatization of Euclidean and Non-Euclidean Geometries as far as the history of Euclid's 5th postulate, in 11th grade students. Our main focus was the students' understanding these three systems of geometry as axiomatic ones and the change of traditional image of mathematics with a humanistic one. Exploitation of ethnographic research techniques helped us gather research data, while all students' presentations were videotaped and analyzed. Our research offered considerable evidence of the effectiveness of the use of Drama techniques as an approach, which helped the development of mathematical knowledge and showcased aspects of mathematics foregrounded by the new philosophy of mathematics.

Philosophy of Mathematics and Mathematics Education: Opening a Closed Relation

The conceptions of our society about the nature and role of mathematics have a significant impact on mathematics education and research. Any assumption about the character and nature of mathematical knowledge contains and submits relevant approaches to learning and teaching of Mathematics (Chassapis, 2005). Research has shown that it is mainly the teachers' ideas about the nature of mathematics and not about the teaching itself, that determine how they teach (Dossey, 1992). These teachers' perceptions influence students through teaching and shape how they see mathematics.

The philosophy of mathematics is the field of philosophy whose task is to explain the nature of mathematics, answering two basic questions: How the mathematical knowledge is justified (epistemology of mathematics) and what are the objects of Mathematics (ontology of mathematics). The bibliography lists a number of philosophies of mathematics, which most of them can be loosely grouped together and described as traditional- Absolutist- philosophies (like Logicism, Formalism, and to some extent Intuitionism and Platonism) and new- Fallibilist- philosophies of mathematics (like Fallibilism, Social Contructivist) (Ernest, 1991). Traditional 'absolutist' philosophies of mathematics view mathematics as an objective, absolute, certain and incorrigible body of knowledge, which rests on the firm foundations of deductive logic. From that perspective it is timeless, superhuman and ahistorical and it is pure, isolated, both value-and culture-free knowledge useful because of its universal validity (Ernest, 2009). The new fallibilist philosophy of mathematics rejects absolutism as there are not absolute and eternally incorrigible foundations for mathematical knowledge, due to profound philosophical problems including Gödel's incompleteness theorems (Davis and Hersh, 1980; Lakatos, 1976; Kitcher, 1983) and reveals mathematics as human, corrigible, historical and forever changing (Ernest, 2009).

In addition to 'philosophy of mathematics' as an academic discipline, the term 'images of mathematics' is met. They are defined as a system of beliefs or views, which may only be partly expressed, as well as being partly made up of tacit inferences assumptions and beliefs about the nature of mathematics (Ernest, 2009:46). We also meet two groups of images of mathematics: The traditional image of mathematics (as difficult, cold, rigid, abstract, theoretical) which resonates with traditional absolutist philosophies of mathematics and the humanistic image of mathematics (human and personal, approachable and accessible) which as the new philosophy of mathematics gives an emphasis on the centrality of the processes of human inquiry to mathematics (Ernest, 2009). It is argued that although these two philosophical positions have a major impact on the ethos of mathematics classrooms, there is no direct logical connection (Ernest, 1995). Images of mathematics are a large component of learners' attitudes and beliefs about mathematics (Ernest, 2008). The traditional image is often associated with negative attitudes to mathematics, while the humanistic image is typically the adjunct of positive attitudes to mathematics (Ernest, 1995; 2009). Thus developing positive image in learners is important for individual learner benefits (Ernest, 2008).

The new philosophy of mathematics, according to Ernest (2009) emphasizes a number of novel and hitherto neglected features that have significance for the teaching and learning of mathematics as:

- *The reconceptualization of mathematical knowledge as a fallible human invention,* results in moving away from the traditional school image of mathematics as something fixed with only one right answer, right method and the removal from the teaching model that favors algorithmic thinking and 'productive' character presentation.
- *The redefinition of mathematical knowledge as cultural and social construction* has as result a culturally responsive mathematics education, which through incorporating elements of the history of mathematics into school mathematics acknowledges the panhuman origins of mathematics.
- *The reconceptualization of mathematics as a value-laden field with social responsibility,* which gives emphasis to cultural values of the social groups and contexts in which mathematics is made, results the social responsible role of mathematics in educating young people. While traditional (absolutist) philosophies of mathematics assert that mathematics is objective and neutral, culture-free and free of ethical and human values, the image of mathematics they promote is itself value-laden (Ernest, 1991; 2009) with predominance of abstract over concrete, former over informal, objective over subjective, justification over discovery, rationality over intuition (Ernest, 1991). Regarding mathematics and social responsibility, mathematics education has the potential to contribute to the development of critical citizenship and support democratic ideals (Skovsmose, 2004), as well as the development of citizens who can participate actively and responsibly in discussions and processes in which the individual is required to take part in personal and public decisions (Skovsmose 1996:1267).

This research focuses on exploring the dynamics of Drama in Education techniques in the development of mathematical knowledge and in the creation of a humanistic image of school mathematics, through a didactical experiment in the teaching of geometry, view from of the new philosophy of mathematics perspective, which emphasizes in the aforementioned aspects of mathematics.

Drama in Education and the New Philosophy of Mathematics

Drama in Education (DIE) can be a highly structured pedagogical procedure utilizing specific rituals and techniques of dramatic art aiming to focus participants' attention towards *the process* of participants' experience and not on the final product (Alkistis, 2000). It, potentially, constitutes a teaching approach that can embrace collaborative, active learning through experience, while giving participants the opportunity to develop acceptance, understanding, creativity, curiosity, self-consciousness, self-esteem (Wagner, 1999, Wooland, 1993). The use of Drama techniques in education has been proposed among others, as a context that offers innovative ways for teaching varied disciplinary curriculum areas and as creative ways for the students to reflect on broader learning issues (social, political). As far as mathematics teaching, Drama techniques can create the context for teaching a concept, an idea or an event and offers opportunities for exploring mathematics in a variety of historical, social or cultural contexts. The research results concerning the effects of Drama in teaching and learning Mathematics are very encouraging in students' understanding and retention of mathematical notions (Saab, 1987; Omniewski, 1999; Fleming et all, 2004; Duatepe, 2004) and in creating positive impact in their attitudes towards mathematics (Duatepe, 2004). Drama techniques help students to experience the dimension of mathematics as a cultural construction as well as the aspect of mathematics as a socio-political 'tool' (Kotarinou, 2010) and also seem to be a suitable framework that offers ways for integrating Mathematics with varied disciplinary areas of curriculum (Stathopoulou et al, 2012).

Our teaching experiment was designed to introduce students to an epistemological rupture in the history of mathematics, assuming that this would have the ability to challenge students' beliefs about geometry and generally their image of mathematics as a science of absolute truth. The discovery of non-Euclidean geometries is such a rupture in the history and evolution of mathematics, through the separation of reality from mathematical space and through the conscious realization that mathematical structures, in their role as models, are the new mediating artifacts to explore space. (Hegedus & Moreno- Armella, 2011). As characteristically Hegedus and Morena state 'With Euclidean ontology a mirror was placed between the world and mathematics. Non Euclidean geometry broke the mirror' (Hegedus & Moreno- Armella, 2011:379)

Euclidean methodology has developed a certain style of presentation, the 'deductivist style', which consists of a cumbersome list of axioms, lemmas and /or definitions which is followed by true propositions and valid inferences (Lakatos, 1991). Thus, Mathematics is presented as an ever-increasing set of eternal immutable truths, while the entire struggle and the adventure is hidden (Lakatos, 1991). As Lakatos (1991:142) characteristically notes 'the successive tentative formulations of the theorem in the course of the proof-procedure are doomed to oblivion while the end result is exalted into sacred infallibility'. For this reason, we decided in our teaching experiment to reveal the process from the axiomatic foundation of Euclidean geometry until the discovery of non-Euclidean geometries, having activities concerning the struggle of mathematicians of the wider Islamic world and later by the mathematicians of the Renaissance to prove Euclid's 5th postulate, which still remains to Lethe in school mathematics.

The Research

The research focuses on exploring the dynamics of Drama in Education Techniques in teaching Geometry, through a didactical experiment (Chronaki, 2008). In this paper we will try to answer the question whether and how DIE contributes to the development of mathematical knowledge and the emergence of a humanistic image of school mathematics regarding teaching through 'Drama techniques', the axiomatization of Euclidean and Non-Euclidean Geometries, as well as the history of Euclid's' fifth postulate.

The setting: The research was carried out in a group of 26 (11th-grade students) from different directions of studies in the 2nd High School of Ilion (Athens, 2010-11).

The method: Exploitation of ethnographic research techniques helped us gathering research data: a) Observation of students' mathematics class in their ordinary lesson and participatory observation during the teaching experiment for exploring the way Drama in Education techniques affect the instructional classroom norms and practices b) Questionnaires concerning students' beliefs about geometry, before the teaching experiment c) Students' interviews (two months later) regarding mathematics achievement and retention of knowledge of each student, their image of geometry after the teaching experiment, as well as the reasons of students' motivation and active participation in the teaching experiment. All students' presentations were videotaped and analyzed regarding the proper use of mathematical notions in their dialogues, while some episodes of students' group work were audio recorded and analyzed regarding the role of Drama as a mediating tool for the negotiation of meaning and the development of understanding.

The teaching experiment: The teaching experiment —titled "*Is our world Euclidean'*—was carried out by the researcher in teaching role, in 25 teaching periods, during seven weeks, in Geometry, History, Language, Literature and Ancient Greek Language classes. The three main points were: the mathematics per se, the Mathematicians and the historical and cultural context in which these Mathematics have been established. Our teaching aimed at: a) the students understanding of the axiomatization of Euclidean, Hyperbolic and Elliptic Geometry and the general concept of the axiomatic foundation of a science b) the students perceiving the role of the postulates and redefining the Euclidean Geometry c) challenging students' stereotypical believes around Geometry encouraging them to develop a critical stance towards mathematical knowledge, as absolute, objective and infallible knowledge.

The teaching experiment consisted of the following units:

1. Euclid's Elements and the axiomatization of Euclidean Geometry (6h): The relation between Euclid's axiomatic foundation of Geometry and Aristotle's' 'Logic' was studied as well as the definitions, the Postulates and Common Notions from the Book I of Euclid's 'Elements'. Students used the Drama conventions as 'role-playing', 'reportage', 'alter-ego', and 'interview' to present the axiomatization of Geometry by Euclid.
2. Euclid and the historical, cultural and political frame of his era (4h): A digital presentation was held by the researcher, concerning Alexandria in the Hellenistic period, while excerpts from the book "The Parrot's Theorem" were read. The chapter 'Euclid's conceit' from J. P. Luminet book 'Euclid's bar', presenting the mathematician Euclid and his era, was read expressively by some students, while some scenes of the same chapter were dramatized.
3. 'History in shadow': the controversy of Euclid's Fifth postulate till 18th century (5h*)*: A combination of 'Shadow Theatre' and 'role playing' was used for presenting the unsuccessful efforts of Arabs mathematicians Thabit ibn Qurrah, Al-Haytham, Omar Khayyam and Nasir al-Din al-Tusi, as well as Saccheri and Lambert, to prove the famous Euclid's fifth postulate.
4. János Bolyai, Lobatscevski, Riemann, the founders-creators of non Euclidean geometries (3h): After having studied the biographies of the aforementioned mathematicians, different Drama techniques as 'Letters', 'Role on the wall', 'Conscience alley', 'Conflicting advice' were used for presenting their work and some snaps shots of their lives.
5. Hyperbolic Geometry and Poincare model (6h): Students studied a chapter from Ian Stewart's book 'Flatterland' concerning Poincare model of Hyperbolic Geometry and used ICT (Interactive Java software 'NonEuclid' by J. Castellanos, Joe Austin, Ervan Darnell, and Maria Estrada) for visualizing the model, the axioms and basic concepts of this non-Euclidean Geometry. Then Drama technique 'Radio-broadcasts' was used for presenting 'Hyperbolic' Geometry and its Poincare model.

6. Spherical Geometry and the axiomatization of Elliptic Geometry (1h): Students studied the axioms and the basic notions of Spherical and Elliptic Geometry through 'Lénárt sphere' and other haptic tools. A role-playing activity was used for the evaluation of knowledge.
7. The film: A documentary film entitled 'Our lives with Euclid' was created around these drama-activities with the students in the role of narrators, who wrote their own texts of the narration after having studied the relevant literature.

In every topic of the experiment, initially, a lecture was given by the researcher helping the students to acquire suitable knowledge regarding their presentations. Subsequently, the students worked in teams using appropriate bibliographical recourses, haptic material or ICT and after rehearsing they performed their presentations using different drama conventions. At the end of every unit a short discussion for reflection followed, while at the end of the teaching experiment an entire class period was dedicated for the same reason.

Results

Analysis of the dialogues in students' Drama performances suggests that the groups of students conceived the mathematical notions that they had been assigned to present, integrating them correctly in their dialogues. The students' answers to the interviews, two months after the end of teaching experiment, which aimed to evaluate each student understanding and permanence/retention of mathematical notions, indicate that Drama based instruction had positively affected students' learning and retention of the axiomatization of Euclidean and Hyperbolic Geometry, making learning geometry notions more meaningful, easy, permanent. This finding related with students' achievement supports the one of previous studies (Duatepe, 2004; Omnieski, 1999; Saab, 1987) which provided evidence of the efficiency of drama based instruction in facilitating understanding of mathematics concepts in primary and high school level.

- (I) In the way we did all these, I think that one learns more easily. What we learned wasn't designed for learning by heart or to show to the teacher that we really learned that. I think it was easier to learn in this way and to retain this knowledge in our mind.
- *(St.) Some of the concepts were too difficult for me to explain them to the others, but trying to help the others you teach yourself..., trying to explain it to the other, you actually see how it's done.*

Through students responses in the interviews we tried to detect the "image" of mathematics that they formed throughout this experiment.

I) ***Mathematics as a cultural and social construction****:* Students experienced a diachronic evolution of geometry that was connected with the historical, social, economic and political conditions of each era.

- (St.) We realized that in order for the science to be evolved, there needs to be evolution in all other areas first, starting with financial areas and then cultural ones.
- (A) The historical connection of mathematics is very important. Mathematics seemed like having come from heaven. We had just been told the 1 and 2 and the numbers and the calculations, all ended there.

The introduction of mathematics history made geometry meaningful to students. *"(Tat.)* (*I saw) that geometry definitely is something interesting and has great history and that it is not something that has no meaning. It is certainly meaningful*."

II) Mathematics as a human creation: Through the efforts of proving Euclid's fifth postulate and through the mathematicians' biographies, students perceived mathematics as a historically evolving human creation and also realized that other cultures also, have contributed to what we define as Western mathematics.

- (V.) Previously, I thought that the knowledge of mathematics came from God, from heaven. I couldn't be in the process of thinking that someone thought of it. Basically I was thinking of that, but I was wondering: how can one think of it? I was telling myself he was born that way. But eventually, through this I realized that all these people make research, read, learn.

Students emphasized the continuous and strenuous effort that was made by the mathematicians of the wider Islamic world and later by Renaissance mathematicians, to prove the fifth postulate. *"(Sof.)...I remember that the whole thing gave them a hard day. I remember this, that they (these mathematicians) resulted in mistakes, many mistakes, but, it's okay, one learns from mistakes."*

Students in their responses highlight the dedication of Bolyai, Lompatsevski. and Riemann in mathematics and the perseverance in their objectives. "*(Mar.) ...I saw that these people in a great part of their lives were dealing with mathematics and they had set a target, trying to reach it. It was very interesting, all this effort to prove something, really interesting."*

III) Mathematics as a creation under constant negotiation: Active involvement in the teaching of non-Euclidean geometries provoked students' perception about mathematics as a science of the absolute truth. Their involvement in this procedure made students to perceive Mathematics as corrigible and as a creation under constant negotiation, modifying thus their epistemological beliefs about mathematics and provoked the dominant belief that Euclidean geometry is the only model which interprets and represents our real world, shaking thereby and other certainties.

- (St.) Certainly the plasticity of mathematics emerged and the way mathematics are created and changed depends on the needs of the mathematician, of the scientist and of the human being generally. It is clear that mathematics is a complex notion which is not restricted to only one way of understanding reality…
- (Ang.) Finally there are and other views and we cannot say which is absolutely right and which not.

The theme of the teaching experiment showed students some mathematical aspects which were not known to them before, which they intrigued them for geometry per se, as well as for additional research on the topics dealt.

- (G.) I got more involved and started to look them up in my course book, cause I thought that they took it from the book, somewhere, so I read all the history notes.
- *(S.) The fact that I saw other geometries it picked my interest and to tell you the truth, I started looking for information at home and on the Internet and I really enjoyed.*
- (A.) It seemed to me that there are other aspects to geometry, much more interesting than those you see in class, so eventually it's worth putting more effort to it; it's not a good idea to give up on geometry so easily.

IV) ***The role of Drama in Education***: The contribution of DIE in the whole teaching experiment was decisive in the teaching experiment. "*(V.) It was completely different than just writing stuff, to present, to feel it yours and try to pass it to others. It was very nice."*

The DIE has been the main motivation for the active participation of all students in the teaching experiment due to:

- The experiential nature of Drama. *"(A). We felt as if we were discussing with others in order for them to learn, as we were the teachers ourselves, as long as Euclid, Gauss and Lobachevski. We were more involved in profound knowledge."*
- The drama creative character, which gave them the opportunity to express themselves in their own way and for everyone to bring out his special abilities and talents. *"(Vir.) It was something new, it was so very different for everyone,.., and very creative and everyone could show his abilities, the different ones that everybody has".*
- The impact that drama had on students' identities as mathematics learners, stimulating their confidence as individuals who could express their opinion and participate in the writing of the texts and in different drama presentations. *"(H.) Yes, surely (I felt more capable) because before I had hardly participated, while here I said my opinion, I wrote and I took part in the presentation. I couldn't have thought of this before."*
- The cooperation of students, collectivity and solidarity between them. '*(Tat.) Everyone felt more sure of himself, had no anxiety and knew that he had some help".(Vir.) This feeling that we are all together and we must do our best for us to be then satisfied and for audience and those watching to be delighted.*
- To students well-being "*(Z) There was laughter and fun in the way we did all this, with the theater and the cooperation...(V.) It was a combination of coursework and entertainment."*

Conclusions

Our research offers considerable evidence of the effectiveness of the use of Drama techniques to challenge the dominant image of students regarding mathematics as an absolute, objective and infallible knowledge and free of ethical, human and cultural values. Students' involvement in Drama conventions promoted participatory performance and gave a context that offered innovative and creative ways for the students to modify their epistemological conceptions about mathematics and to develop critical thinking about 'mathematics in society and history'. Contrary to a conventional lesson, which emphasizes the solving of formal problems –often de-contextualized— students faced a non direct mathematical problem (is our world Euclidean?) involving nonetheless mathematical notions. During the teaching experiment the key role of the historical and social context in which mathematical concepts were created was illustrated and the contribution of different cultures in the creation of mathematics was showcased. Drama techniques were an alternative approach in the creation of the appropriate learning conditions where all the students participated in teaching/learning process, experienced all these dimensions of mathematics, not only mentally but also emotionally and physically and became critical thinkers and decision makers in the classroom setting, skills vital to the development of democratic citizenship.

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Comparative Study About Gender Differences in Mathematical Modelling

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In this paper three different modelling tasks are analysed in order to get insights in gender differences in mathematical modelling. Several school achievement studies indicate that gender differences concerning the mathematical knowledge exist in favour of boys but this result is balanced out when assessing problem-solving contexts. But it is questionable whether these international tests contain items which require real modelling activity in terms of passing through a whole modelling cycle. Therefore, three different modelling tasks were taken as a basis to reveal gender aspects in a real modelling context. The results of all three studies show, in accordance with PISA studies, that there are in general no significant gender differences, even though there are some significant results regarding specific grades. Furthermore, in general the boys cannot benefit from their advantage in mathematics knowledge when it is a question of mathematical modelling.

Introduction

Meanwhile there is a broad consent about the necessity of mathematical modelling in the curricula. Many countries, among them also Germany, have included modelling tasks in their teaching practice. To evaluate the performance of students several school achievement studies have been implemented especially in the last decade. Internationally known is in particular the Programme for International Student Assessment (PISA) and the Trends in International Mathematics and Science Study (TIMSS). TIMSS is an international assessment of mathematics and science knowledge and PISA seeks for testing literacy in reading, mathematics and science. In these studies, besides many others aspects, gender differences have been evaluated. The question arises to what extent the tasks in these studies do map mathematical modelling competence as a whole. According to Turner (2007) the test items in PISA only “promote an interest to modelling but have a low level of complexity of modelling activity” (Frejd, 2012). Therefore we analysed three existing studies based on real modelling tasks which include all modelling subcompetencies (see the modelling cycle of Blum and Leiß (2005)), according to gender differences. With this we also want to evaluate whether the advance of boys’ regarding mathematics knowledge (Budde, 2009) is also reflected in the specific area of mathematical modelling.

The studies

The objective of the studies was to evaluate the modelling competence of students. Therefore we developed three different modelling tasks which require passing through a whole modelling process. The design of the studies encompassed a short film of 100 seconds illustrating the underlying situation (see e.g. http://www.youtube.com/watch?v=jJZsy-Y3c5M) followed by 25 minutes of seatwork. Finally we assessed the solution approaches based on the phase reached in the modellin g cycle of Blum and Leiß (2005), since a transition between on phase and another is a cognitive obstacle (Blum, 2007). Therefore we assigned levels to each phase of the modelling cycle (see Figure 1) and worked out characterisations of these such that the student solutions could be easily rated (Ludwig & Xu, 2010).

- Level 0: The student has not understood the situation and is not able to draw sketches or to concretise the problem.
- Level 1: The student understands the given real situation, but is not able to structure and simplify the situation or cannot find connections to any mathematical ideas.
- Level 2: After investigating the given real situation, the student finds a real model through structuring and simplifying, but is not able to transfer this into a mathematical problem (the student creates a kind of word problem about the real situation).
- Level 3: The student is also able to translate the situation into a proper mathematical problem, but the student cannot work with it mathematically.

- Level 4: The student is able to pick up a mathematical problem from the real situation, works with this mathematical problem mathematically, and gets mathematical results.
- Level 5: The student is able to reproduce the mathematical modelling process and validates the solution of a mathematical problem in relation to the given situation.

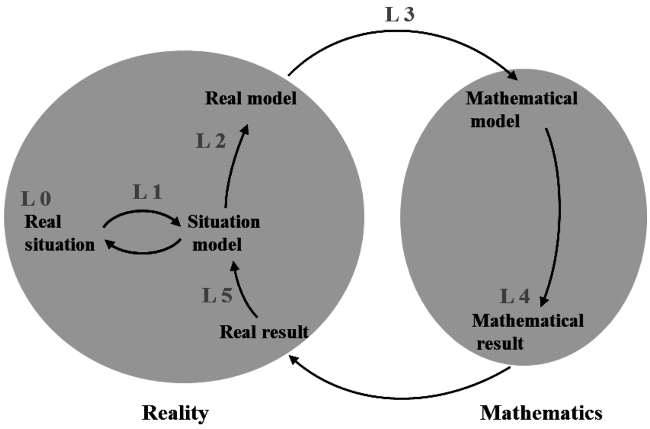


Figure 1. Classification of levels into the modelling cycle of Blum and Leiß (2005)

The aim of the present paper is to analyse the three studies with respect to gender aspects to reveal possible gender differences concerning the ability of solving modelling tasks. With this repeated analysis of existing studies we get new interesting insights in the solution behaviour of modelling tasks of girls and boys which may support the process of integration of modelling tasks in school practice.

In the study of Ludwig and Xu (2010) modelling competence levels of 1108 Chinese and German students from grade 9 to 11 have been investigated based on a modelling task concerning the mathematical background of the peeling process of a pineapple (a characteristic pattern arises), as it is common in China. The students were then asked to find a mathematical explanation why the pineapples are peeled in a spiral way (see Figure 2).

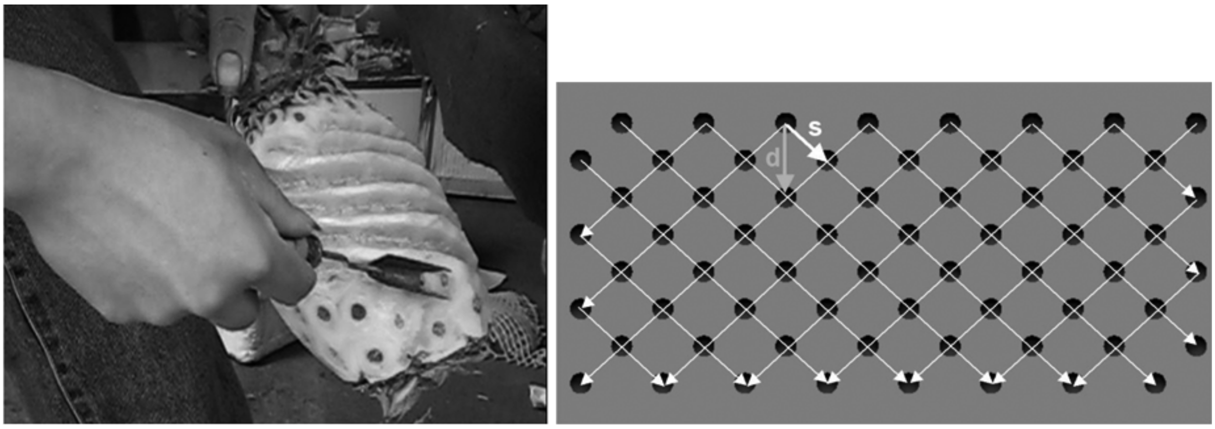
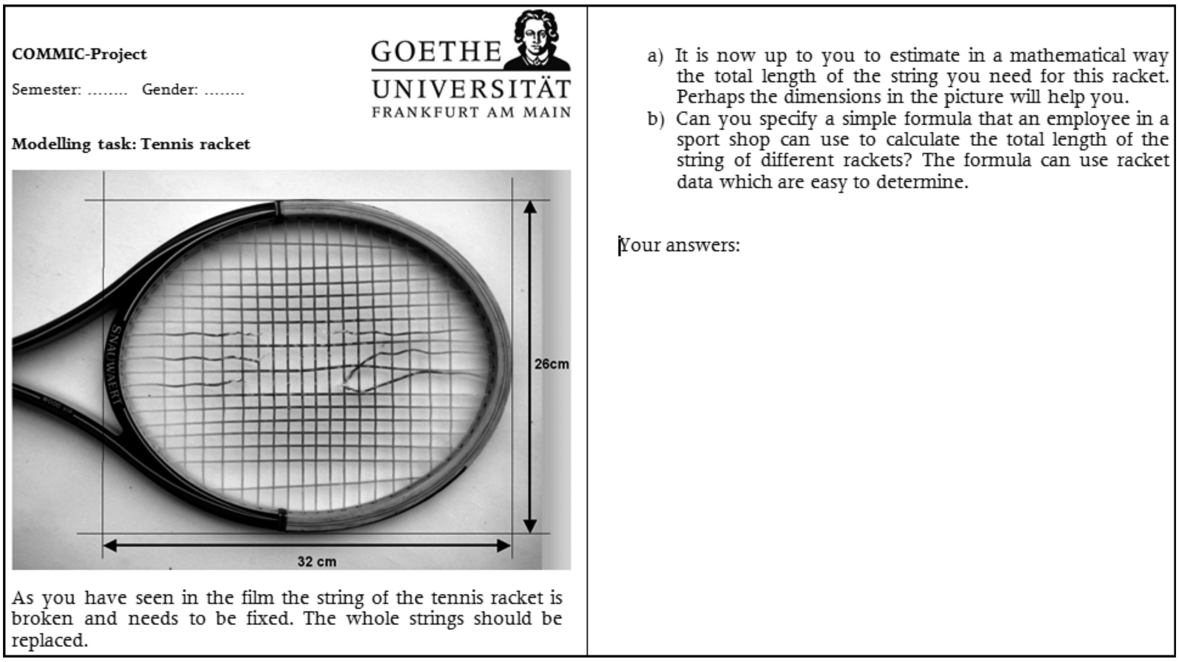


Figure 2. Peeling process of a pineapple and a mathematical model of the given situation

In the analysis emphasis was given on the levels (based on the modelling step reached in the modelling cycle of Blum and Leiß (2005)) accomplished by Chinese and German students as well as on coherences between Chinese and German performance.

The emphasis in the study of Ludwig and Reit (2012) was on the analysis the mathematical modelling competence of students from a wide range of grades. For this purpose we questioned 300 grammar school students from grade 6 to 11 and 176 teacher trainees with main subject mathematics. The central question was to mathematically estimate the length of string needed to restring a broken tennis racket and, as a second question, to establish a general formula for different shapes of rackets (see Figure 3).


COMMIC-Project

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

Semester: .... Gender: ....

Modelling task: Tennis racket

As you have seen in the film the string of the tennis racket is broken and needs to be fixed. The whole strings should be replaced.

a) It is now up to you to estimate in a mathematical way the total length of the string you need for this racket. Perhaps the dimensions in the picture will help you.
b) Can you specify a simple formula that an employee in a sport shop can use to calculate the total length of the string of different rackets? The formula can use racket data which are easy to determine.

Your answers:

Figure 3. Worksheet of the tennis racket task

We were able to identify 4 different solution approaches depending on how the racket shape has been approximated (rectangle approach, circle approach, function approach) or the length has been directly measured by a ruler (direct measurement). Solution approaches which did not lead to an identifiable goal have been assigned to unrewarding solution approaches.

Another study has been performed by Ludwig and students in 2008 where the mathematical modelling competence of 112 low track students (the German educational system is composed of a tripartite structure which differ in the level of qualification) in grades 5 to 8 has been investigated. The initial question was to mathematically deduce the time needed to sew a football based on the explanations and visual impressions of the film.

Figure 4. Picture of a football on the worksheets composed of pentagons and hexagons

Gender aspects of the studies

In the following we analyse the studies above in terms of the correlation of gender and modelling competence. Doing so we either draw back on existing results or we evaluate the respective data again to that effect.

Peeling a pineapple

The focus in this study was to investigate the differences and coherences of German and Chinese students according to their modelling competence. Apart from results showing that mathematical modelling competence is not dependent on the two populations, the study reveals interesting gender aspects among Chinese and German students. In general the modelling performance appeared to be comparable in China and Germany.

Performance differences among the students of the respective country became obvious. A t-test shows that the modelling competence of Chinese girls is significantly better than the boys' ($p = 0.021$), although this result can be partly qualified by a significant difference in grade 9 ($p = 0.010$). From the German perspective there is no significant difference between the modelling competence of boys and girls.

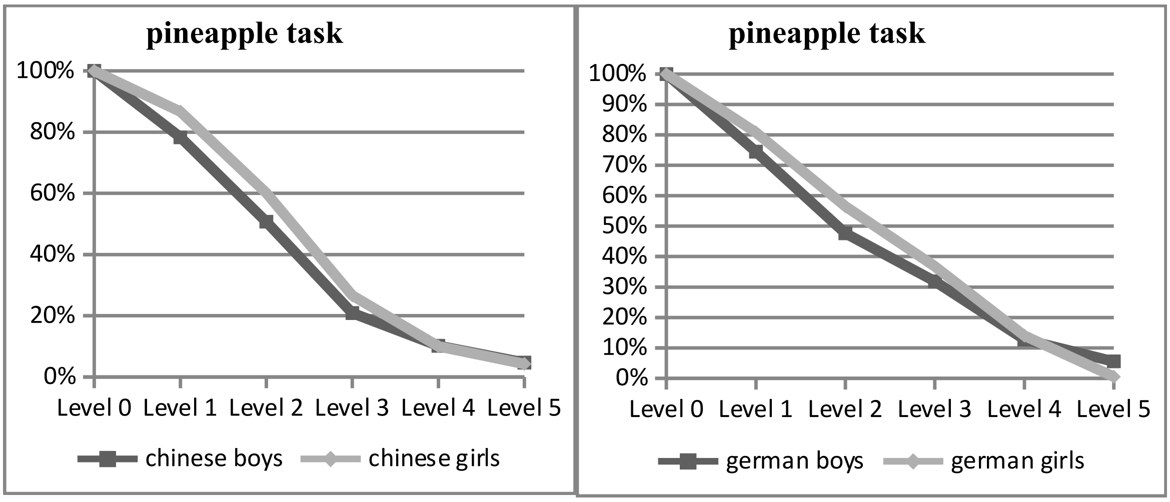


Figure 5. Percentage of boys and girls who stopped on level x

Having a closer look on the levels reached by boys and girls the results indicate that there is no significant difference between the modelling competence of boys and girls in each country.

In an overall context we determined a continuous improvement in modelling competence from grade 9 to 11. Both, boys and girls, show a better performance the older they are, although the results from German girls are not significant. However, the results clearly indicate that there are no general differences in the modelling competence of boys and girls of both populations with respect to this specific modelling task.

Tennis racket task

Comparing the modelling results of boys and girls, the tennis racket study revealed no significant differences in their performances. Figure 1 shows, that there is a strong similarity in the distribution of boys and girls. However, the percentage of boys reaching only level 0 is remarkable compared to the girls where the vast majority reached at least level 1.

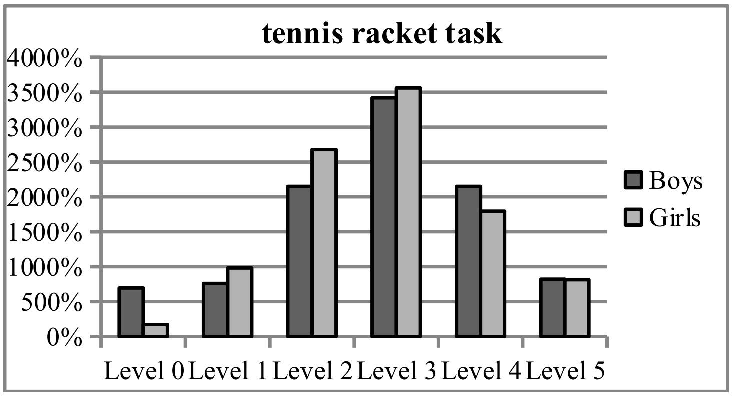


Figure 6. Levels reached by boys and girls

To statistically substantiate this allegation we implemented a Mann-Whitney-U-Test (Bortz, Lienert, & Boehnke, 2008). From the resultant data we cannot conclude a significant difference in modelling performance of boys and girls ($z = -0.29$, $p = 0.77$). Figure 2 also reflects this result since it is clearly visible that there are no general differences in performance between boys and girls.

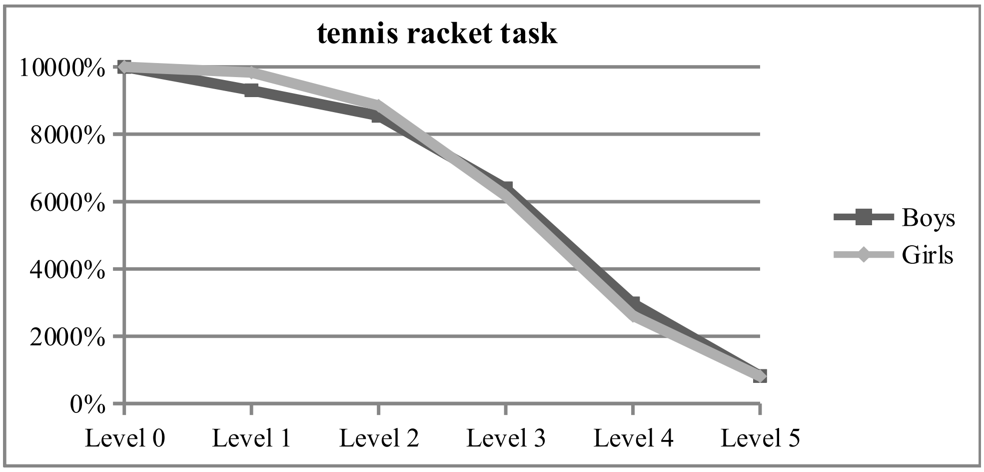


Figure 7. Percentage of boys and girls reaching level x

Sewing a football

In this study the focus has been on 5th to 8th graders (n=132) from German low track schools. An evaluation of the gathered data showed gender differences within the grades but this phenomenon is compensated when regarding the distribution on levels.

In particular boys outperformed girls in grade 6 and 8; whereas we could not determine a gender difference in grade 5. Only in grade 7 girls are in advance of boys. Boys of grade 8 also reached the highest average level. The largest gender difference of approximately one level appeared in grades 6 and 7. From grade 5 to 7 the girls were able to continuously improve their modelling competence, whilst falling back in grade 8. The boys' performance was subject to large variations.

By regarding the levels of boys and girls among all grades, the results from above are qualified (see Figure 8). The distribution of boys and girls on levels closely resemble. 40.8% of the boys and 36.6% of the girls reached level 2, 3 or 4. This means that slightly more boys than girls overcame level 1. However, this result is not statistically significant which is why we can assume an overall comparability of modelling competence between boys and girls.

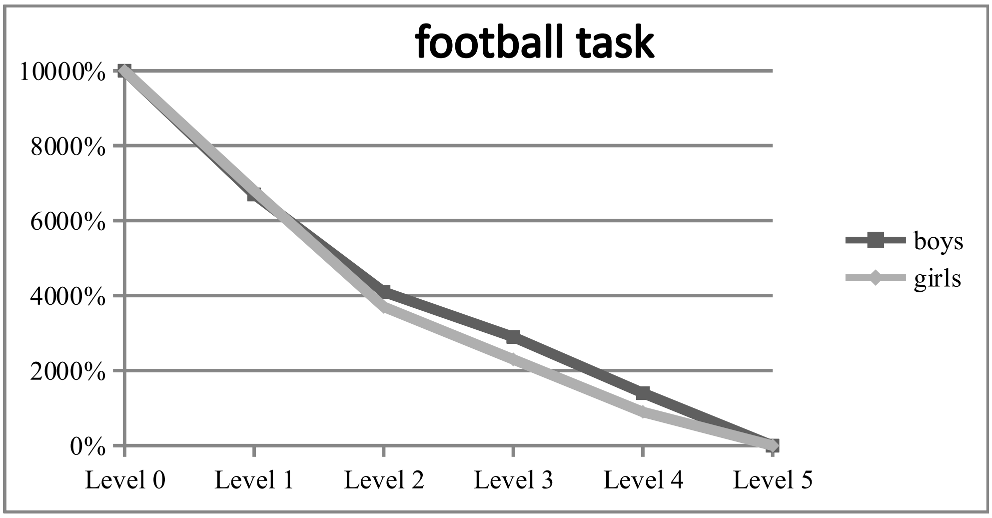


Figure 8. Distribution of levels among all grades

Conclusion

The three analysed studies equally confirm our assumption of a gender independent modelling competence, although there are some gender differences regarding specific issues. Especially the Sino-German study revealed different modelling competences of Chinese boys and girls within individual grades. However, this result should not be overstated in view of a statistic significance of one specific grade. The football study indeed shows that neither boys nor girls are definitely in advance, since the distribution of levels is subject to considerable fluctuations from grade to grade. This result indicates that modelling competence is rather not gender dependent but depends on other variables like cognitive development, though this aspect is subject of a further study. The data of the tennis racket study support a general comparability of boys' and girls' modelling competence.

Our result is in accord with the results from PISA (Programme for international student assessment). Although boys have a performance advantage in mathematics, in most countries no statistically significant gender differences can be verified in the context of problem-solving (OECD, 2009; Klieme, et al., 2010). That means that the boys' mathematics strength has no direct effect on their ability to cope with problem solving tasks. A remarkable difference of our studies and PISA is indeed that the aspect of mathematical modelling has been realized in our studies by one single real modelling task, whereas the tasks in PISA cover at most subcompetencies but do not require performing a whole modelling process. As a consequence the result of our studies is all the more meaningful according to gender differences in modelling since it is in accordance with the representative PISA study and reflects modelling competence in a more detailed and adequate way.

In the TIMSS (Trends in International Mathematics and Science Study) studies the picture is almost the same. Among the 8th graders gender differences in average mathematics achievement are either small or negligible. However, all statistically significant results favoured boys rather than girls (Mullis, Martin, Fierros, Goldberg, & Stemler, 2000). But the investigations in TIMSS confine themselves to mathematics and science and do not consider problem solving or mathematical modelling as separate item or area (Martin & Kelly, 1998).

In summary, the three different modelling tasks of our studies did not reveal a significant gender difference in mathematical modelling. In view of the fact that boys rather than girls show better results in mathematics (Mullis, Martin, Fierros, Goldberg, & Stemler, 2000; OECD, 2009), this result implies that also other abilities than mathematical knowledge are required when dealing with mathematical modelling tasks (cf. Doyle, 2005). This assumption is based on comparative results from PISA, TIMSS and our studies though, and cannot be determined by considering our studies individually since we did not ascertain data about the mathematical knowledge of the participating students.

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Schematisation in Biological Diagrams: A historical Analysis

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There has been a long tradition of producing depictive diagrams which closely resemble the objects they represent in the teaching and learning of concepts in biology. There is also a perceived need to make diagrams accessible and meaningful to students, quite contrary to the mechanical manner in which it is perceived and used. While this is an important pedagogical stance, the history of documentation of concepts such as: Linnean taxonomy, Darwinian evolution and Mendelian genetics suggest that there was no privileging of one form of diagrams over the other. There has been a range even in the history of taxonomic diagrams. A seemingly complex concept such as the cell was first documented through a detailed depictive representation. There is a tendency however, for concepts which are more abstract, such as evolution by natural selection and Mendelian genetics to rely on schematic representations. There also does not seem to be a clear trajectory from one form to the other within the development of understanding of the concept, as this is dependent on the nature of the concept itself and the academic inclination of researchers. Through a historical analysis, this paper argues for using both depictive and schematic diagrams in the teaching and learning of any concept since they have different purposes, and both are required for understanding and communication.

Privileging the 'depictive' diagram

All diagrams involve a level of schematisation. Some closely resemble the objects they represent whereas others are less likely to do so, at varying levels. In constructing a diagram (even one which intends to reproduce the features of an object / organism), the artist or person who is drawing exercises judgement, prior knowledge and interest which has a large bearing on the production. At the other end of the spectrum, we have highly schematised diagrams using signs and symbols which do not resemble the object to be represented at all or very minimally. Processes are very often represented schematically since they have to denote more than a tangible external referent. In the Indian school biology classroom, there has been a tradition of making children produce depictive diagrams which are expected to closely resemble the objects they denote. These exercises consist of copying diagrams from textbooks, keeping detailed 'record books' or 'journals' often of textbook diagrams which are 'ideal', irrespective of what observation through the microscope or of laboratory specimens suggest. Very rarely are there questions encouraged about the differences in observations and textbook diagrams and if they do arise, the teacher finds it challenging to explain this difference. Diagrams representing processes and more schematic representations are uncommon.

One may argue that every child can be taught to make a good depictive drawing; such a skill is as important as reading and writing and enough importance is not being given to pedagogical practices which support this at the school level. On the other hand, there is also a perceived need to make diagram-drawing accessible and meaningful to students, contrary to the mechanical and 'supplementary' manner in which it is commonly perceived and used (Mathai and Ramadas, 2009). While this is an important pedagogical stance, it is instructive to ask the question why a privileging of exact depictions took place in the teaching and learning of biology. Through a historical analysis, this paper seeks to open and explore the questions: What was the relationship between the depictive and schematic diagram in the history of biology and what were the circumstances when either or both were used? Did one form precede the other? If so, what were the conditions under which this happened? I will examine the coming to being of the schematic diagram using evidence primarily from the history of documentation of the concepts of Linnaean taxonomy (classification of plants and animals), Darwinian evolution, and Classical Genetics.

A visual culture: 'Seeing is Knowing'

Fox Keller (2003) writes about the long tradition of visual forms of evidence in understanding molecular embryology, and the sustenance of the popular statement: 'seeing is knowing' with reference to the nature of evidence in biology. In the history of taxonomy too from the time of the Greeks, the emphasis was on the production of diagrams as a result of direct observation. Otto Brunfels' three volumes of 'Living Illustrations of Plants' in the mid-sixteenth century contained accurate drawings and descriptions of 238 plants (Ronan, 1983). Rondelet's 'The Complete History of Fish' also in roughly the same period included a detailed drawing of a sea urchin, which is arguably the earliest surviving picture of the dissection of an invertebrate. (On the other hand there are also examples of erroneous deductive reasoning unsupported by observations which led Aristotle to conclude in his 'History of Animals' that human males have more teeth than human females).

Even the first drawings of cells from the branch of a cork tree (Figure 1) made by Robert Hooke in his 'Micrographia' were depictive as were his other drawings of various creatures such as the flea, louse, etc. In the Indian tradition, the Mughals with a deep interest in wildlife made several detailed depictions of the animals around them and those which were hunted, in splendid colour along with context and emotions (Figure 2). Rangarajan (2001) captures this when he writes "Mughal techniques of observation and record could be the envy of the modern zoologist and the emotions expressed would be familiar to today's animal lover".

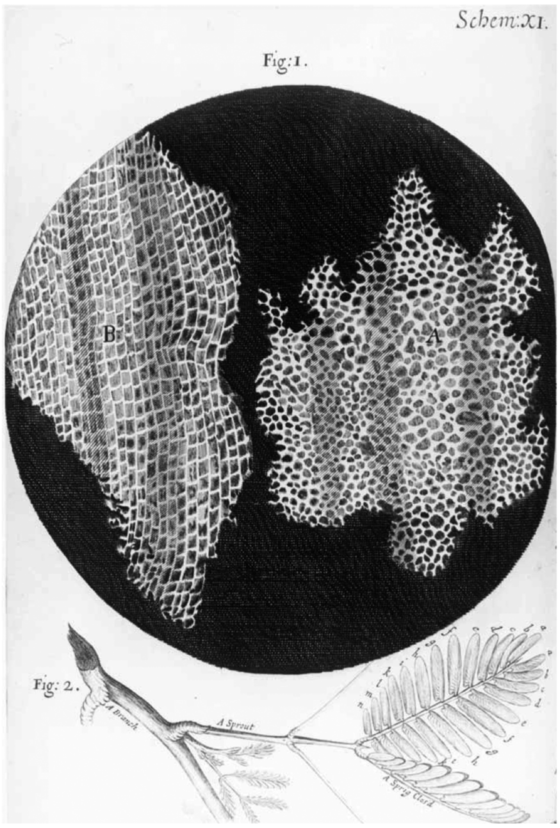

Figure 1. (left): Hooke's depictive representation of cell; Figure 2. (right): Akbar's painting "Lion at rest", c. 1585.

If it were indeed a depictive, exact tradition which informed the field of biology, what circumstances could have led to the production of schematic diagrams?

Schematisation as a journey towards the development of language

A widely prevalent view is to consider schematisation as the road to the development of the system of signs and symbols we call 'language' (Tversky, 2001). Though the argument favouring increased abstraction leading to highly schematised symbols akin to that of a language has value, there is also evidence from art history to substantiate the view that "precedence does not imply derivation" (Karmiloff-Smith, 1996). Neurophysiological evidence indicates that visual representation is distinct in being organised spatially and perceived simultaneously as opposed to language which is organised, read and written sequentially (Farah, 1989).

Schematic diagrams in taxonomy: capturing similarities through simple forms

Though diagrams in taxonomy tend to be depictive in presenting details of morphology and anatomy, there were early precursors to the development of schematic diagrams in this discipline too. In the diagrams of Carl von Linnaeus (1735), the father of modern taxonomy, we see simplified, idealised representations of leaves. This idealisation brings out the merit of line drawings in conveying only what is intended or required. Though the diagrams in this case did not make use of signs and symbols, they are schematised by not including extraneous details which may deflect attention from the intended focus as presented in Figures 3a and 3b.

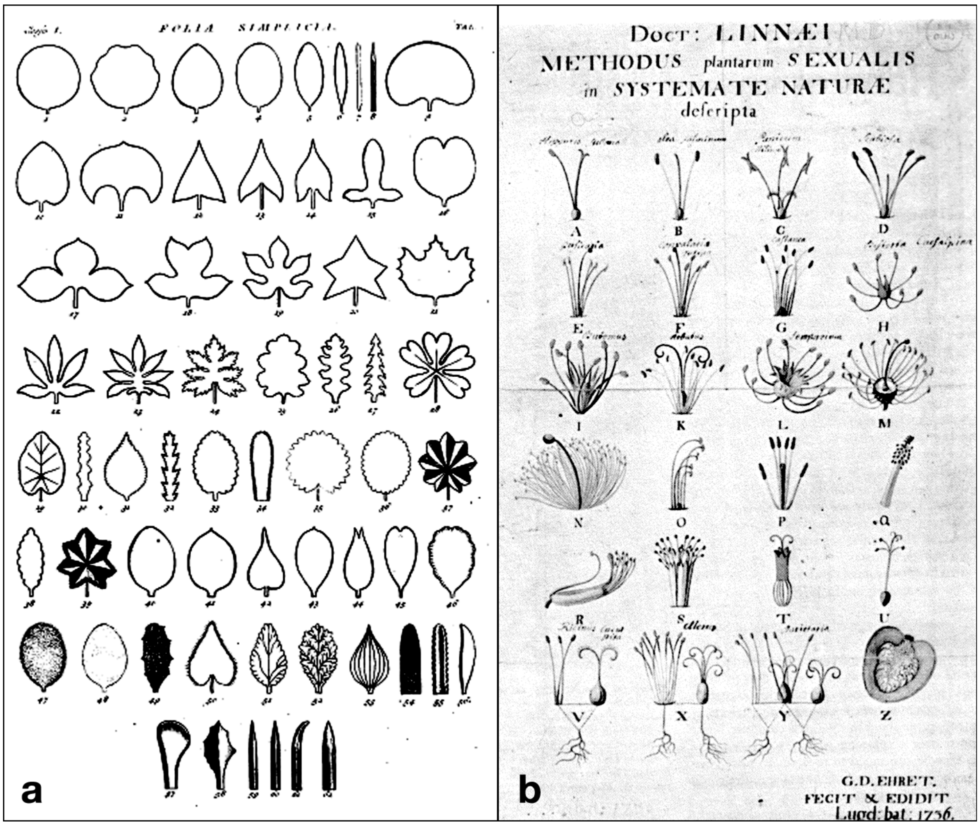

Figure 3a & 3b. Linnaeus's schematised diagrams of the structure of leaves and flowers (1735)

Taylor and Blum (1991) relate the increased production of line drawings in the late 19th century an outcome of the printing technology of that period which even though allowed for the production of photographs, led to reduced clarity in their printing. They write: “The crude early half-tone screens tended to drop out contrast and lose detail, prompting a growing use of line drawing to overcome the problem – ironically photography’s promise of detail was undercut by limits to its mechanical reproduction.” Darwin was among the first to innovatively use photographs along with line illustrations in his work: ‘Expression of the Emotions in Man and Animals’ in 1872 (Taylor and Blum, 1991).

Linnaeus in addition to his schematised representations of the parts of a plant, also used symbols such as the flower clock or “**horologium florae**” (Linnaeus, 1751) and classification tables (Linnaeus, 1735). The flower clock categorised flowers based on the opening and closing of petals (what he called “sleep”) using the time labels of a clock (Figure 4). The schematisation in the form of tables (Figure 5) brought out his system of classification of plants and animals based on similarities and differences of morphological characteristics.

Figure 4. Linnaeus's flower clock (1737) from Zivkovic 2012

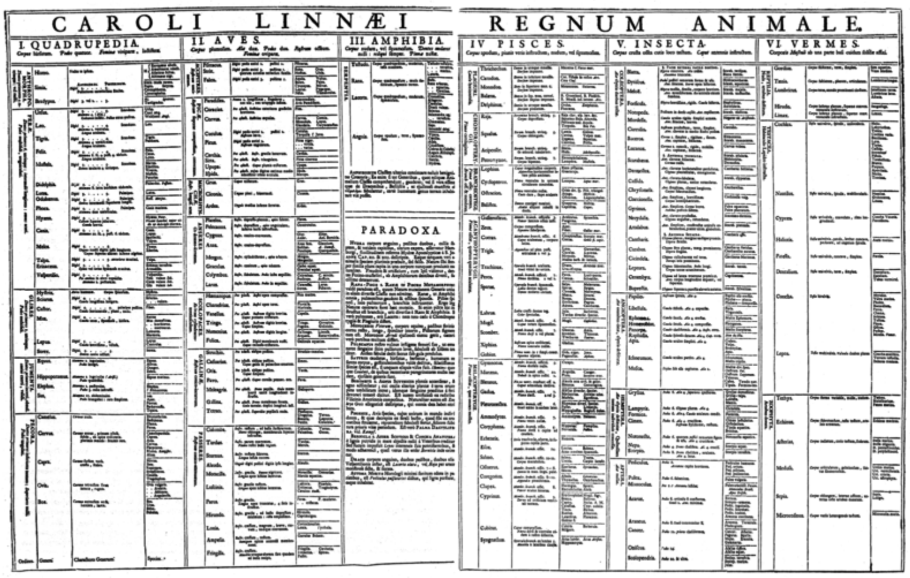

Figure 5. Linnaeus's classification table (1735).

Schematic diagrams as tools to understand abstract concepts / theories

Darwin's 'tree of life' was one of the first metaphors to explain how evolution by natural selection may have run its course. The only diagram in his 'The Origin of Species' is given in Figure 6.

The analogy of the process of evolution to a tree was important and significant, and clearly opposed to the ladder-like understanding prevalent during that period which erroneously claimed the supremacy of man over other all of life. It must however be borne in mind that this level of abstraction was an outcome of several detailed observations and diagrams of specimens, geological structures and fossils made by several natualists including Darwin. The process of natural selection was thus formulated independently by Darwin and Wallace, after encountering countless examples of individual variations through meticulous observations and depictive diagrams.

The tree-like representation has now spawned a variety of specialised diagrammatic languages. The integration of Darwin's theory of evolution with Linnaean taxonomy developed a system of classification based on common descent, and led to the development of newer diagrams in understanding evolutionary biology (Taylor, 1991). Cladistics is one such evolved diagrammatic language, with groups of organisms forming each branch of the 'tree of life'.

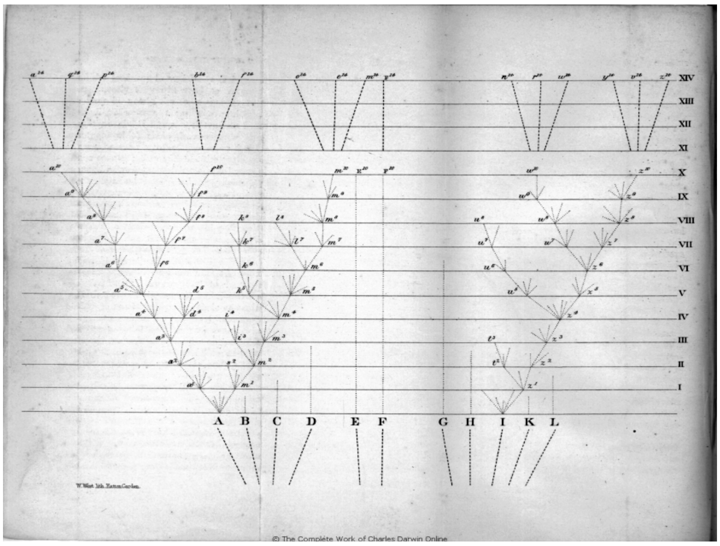

Figure 6. Darwin's tree of life from 'The Origin of Species'

Mendel's careful experiments and detailed observations based on his experiments with pea plants set the ground for the birth of the field of Genetics. His 'Versuche' (1866) did not have any diagrams or photographs. This was surprising since the story of the lonesome monk working away in his kitchen garden, and of the different kinds of crosses seemed to present a very visual description. Mendel is also credited with developing a unique notation of genetic labels to signify the organisms undergoing the cross, the gametes, and the progeny as an outcome of the crosses (Figure 7). This system of notation was extended by Punnett into the Punnett square after the rediscovery of Mendel's work in 1900. The Punnett square proved to be an effective tool for solving simple problems in classical genetics.

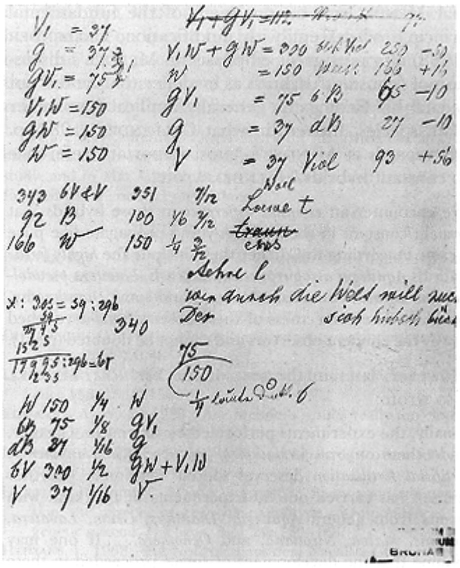

Figure 7. Mendel's genetic symbols in his own handwriting (dated to 1875). From Hartl and Orel, 1992.

The nature of the discipline and inclinations of researchers

In the 1940s and 1950s there was an increased need to understand biological processes at the molecular level, drawing in researchers from the disciplines of physics and chemistry into the field of biology. Attempts to depict processes which were unobservable required schematic depictions. Biology essentially continues to be a "living science" and therefore the privileging of "seeing" (Fox Keller, 2004). On the other hand, theoretical prediction was common in the physical sciences. Schematic diagrams were a reflection of the new field of molecular biology and the differing interests of physicists and chemists with those of the biologists. A classic work 'On growth and form' by pioneering mathematical biologist D'Arcy Thompson (1917), attempted to explain biological structures and processes through mathematical and physical phenomena.

Often, the academic inclination of the researcher has a bearing on the tools for communication. This was the peculiar difficulty faced by Barbara McClintock in communicating using the language of simplicity of physicists and chemists. Such a style was certainly not in keeping with her interests in developmental processes which required more holistic representations such as photographs rather than the cartoons used for molecular mechanisms (Kierns, 1999).

Trajectories of diagram development within a concept

The commonly observed trajectory of diagrams in the journey of understanding a concept is from depictive to more schematised representations. (This was also mentioned earlier, in the case of Darwin's 'tree of life'). The reasons could be many and varied as we have seen from the need to project a particular viewpoint and focus to the difficulty with conveying abstract ideas not only in a depictive form but also in words. Maienschein (1991) recounts the journey of E.B. Wilson's diagrams of the cell from presentation to representation: from photographs to line diagrams, and suggests that this was perhaps a result of an increased understanding of the concept of the cell. The line drawings which he used in his later work were more specific, and indicative of enhanced understanding. The diagrams also changed to draw the reader's attention to the specific features and processes being communicated.

There have also been other trajectories in the history of theoretical sciences such as neuroscience and biophysics (Abraham, 2003). Here the movement is from schematic diagrams to richer, detailed diagrams with the availability and inclusion of more information or content. This as mentioned in the previous Section is again reflective of the background of the researcher and the kinds of research questions which are asked. In more theoretical disciplines, certain exemplars gradually become enriched with more information thereby giving greater explanatory power to the theory (Daarden, 1995).

Schematic diagrams in the teaching – learning process

In conclusion we find that there are various reasons for the birth and sustenance of the schematic diagram which lends enough credence to its inclusion along with depictive diagrams in pedagogical practice. Often the depictive and schematic diagram exist together or are used together to serve different purposes even within a discipline like taxonomy where exact depictions are often the norm. It is also reflective of the tools and techniques used by researchers depending on their area of research and academic background. The trajectory from one form to the other within the journey of understanding a concept is also dependent on the area of research, the researcher and research questions. Therefore there do not seem to be overarching logical or psychological priorities which are independent of context, and can chart a trajectory for pedagogical priorities. Perhaps the trend in taxonomy is to move from depictive to schematic, and in more theoretical areas of the life sciences, from schematic to depictive. Schematic and depictive diagrams have different purposes. The conceptualisation and production of a schematic diagram requires more engagement and longer periods of time since it focuses on specific details to be communicated. Schematic metaphors such as 'Darwin's tree of life' have been instrumental in communicating abstract and complex theories. Hence a more depictive and a more schematic diagram do not need to live uneasily with each other. Both need to be used in the teaching-learning process for effective understanding and communication.

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Can Ethnomathematics Enrich Mathematics Education?

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The paper begins with a characterization of ethnomathematics, with illustrative examples. Next, aspects of its relation to academic mathematics are considered. Then, the connections with the politics of knowledge are explored for a view of mathematics that embraces diversity and, hence, is inherently political. The role of ethnomathematics in establishing mathematics as a multicultural school subject is presented. In the final comment we point to the place of ethnomathematics within the global struggle for diversity.

The ~~intellectual~~ *mathematical* activity of those without power is always characterized as ~~non-intellectual~~ *non-mathematical* (adapted as indicated from Freire & Macedo, 1987, p. 122)

What comes to mind when you hear the word “mathematics”? Many readers are likely to think first of a calculation, a formula, or a geometric figure. Less likely is it that they will think of a human activity such as a design in weaving or pottery, or the construction of a home, which many would not instinctively acknowledge as involving mathematics. By contrast, we define “ethnomathematics” as inclusive of the mathematical practices of cultural groups of all kinds, with profound implications for the place of mathematics within any conception or formal education that honors diversity and connects with the lived experience of the students.

Characterizing Ethnomathematics

There are activities in all cultures in which mathematics is embedded, going far beyond mathematics as an academic discipline. Bishop (1988) highlighted six, namely: counting, locating, measuring, playing, designing, and explaining. Such activities relate to human existence, whether practical (e.g., navigation, finding food), social (e.g., kinship structures), or transcendent of practical needs (e.g., aesthetics, divination). Here are some examples:

- *Counting* practices and tools, both physical and mental, have existed across millennia in great variety (see, e.g., Ascher, 1991; Zaslavsky, 1973). A complex counting system using knotted strings (khipus) used for record keeping was developed by the Inkas, our knowledge of which is largely due to the work of Urton (2003) (and see khipukamayuq.fas.harvard.edu).
- *Locating* is exemplified by navigational techniques of peoples in all environments, a notable case being that of the Pacific islanders. A further example is Pinxten’s profound study of how the Navajo orient, embedded in their conception of space (Pinxten, van Dooren, & Harvey, 1983).
- *Measuring* length throughout history has been based on using parts of the body, as exemplified in Yup’ik everyday practices, studied for many years by Lipka and his team (e.g. Lipka, 2009). As another example, Knijnik (1992) has intensively analyzed cultural practices involving measurement in the context of the Brazilian Landless Movement.
- *Playing* games found in multiple cultures involves many kinds of mathematical reasoning, particularly weighing of probabilities and strategical thinking, for example as studied by Ascher (1991). A wide variety of multicultural mathematical games and puzzles that enhance curricula have been compiled by Zaslavsky (1998, 2003) for classroom use.
- *Designing* reflects the decorative impulse that all humans share (Mukhopadhyay, 2009). The aesthetic enhancement of artifacts, whether plaited baskets from Mozambique (e.g., Gerdes, 2007), or twined spruce baskets made by the Tlingit in Alaska, manifests complex geometrical patterns.
- *Explaining* brings ethnomathematics directly into the sphere of alternative world-views and epistemologies, as in the pioneering study of Navajo conceptions of space by Pinxten et al. (1983), and the analysis of logic among the Kpelle of Liberia which influenced Cole’s (1998) reconceptualization of cultural psychology.

Although the term “ethnomathematics” was first used in the 1930s, reflecting changing conceptions of the human race in anthropology and other disciplines, it was not until the mid-80s that D'Ambrosio (1985) formulated the concept and brought it to international prominence. He proposed an inclusive description for the term as the mathematics practiced by all kinds of cultural groups. Around this time, ethnomathematics as a research movement flourished in "Third World" countries, Brazil and Mozambique being two centers of activity where D'Ambrosio and Gerdes, respectively, provided strong leadership. Reflecting this global awareness, the *International Study Group on Ethnomathematics* began in 1985, and subsequently regional groups emerged, and there are national and international ethnomathematics conferences. D'Ambrosio (2006) continues to lead and inspire in exploring the geopolitical implications of ethnomathematics by focusing on the ethical responsibilities of mathematicians and mathematics educators in a world in which the most important challenge is survival with dignity. Ethnomathematics, as people's mathematics, addresses the cultural, social, and political implications of mathematics that are generally absent from mainstream school mathematics.

As a relatively young field, ethnomathematics is a vigorously contested concept, with no clear theoretical consensus about its epistemological status and ongoing debate about its educational implications. Its alignment with developments within anthropology, the history and philosophy of mathematics, and movements within psychology such as situated cognition and cultural psychology, remain undertheorized. It is largely marginalized by, and critical of, mainstream mathematics education.

Ethnomathematics in relation to academic mathematics

Academic mathematics may be regarded as an abstraction from human mathematical practices, a "purer" form of intellectual activity. There is considerable debate about what it means to discern pieces of formal mathematics embedded in the artifacts and practices of people who do not characterize what they do as mathematics. Freudenthal (1991) has strongly critiqued tendencies among mathematicians and mathematics educators to forget the human origins of mathematics, and the tradition that he founded, carried on in the Freudenthal Institute in Utrecht, emphasizes that mathematics education should reflect the roots of mathematics as a human activity. The dehumanization that is all too common in mathematics education, in the sense of cutting students off from their lived experiences, is a major cause of widespread alienation towards the subject, even among those deemed successful by the standard criteria. This dehumanization has been passionately denounced by Fasheh (e.g. 1997, 2010, 2011).

Pinxten and Francois (2011), amongst others, argue that academic mathematics may itself be characterized as a very particular kind of ethnomathematics, with its specific practices and institutions, carried out by people who identify themselves as mathematicians. Academic mathematics thus has a rich intellectual and social history, till recently dominated by a Eurocentric narrative – uncompromisingly characterized by Raju (2007) as racist. In particular, this narrative fails to acknowledge diverse contributions from India, China, and Arab countries (Joseph, 1991). A related issue is the conception of mathematics as universal and timeless. This conception has been convincingly critiqued by Raju (2007) who argues that there are two major streams of mathematics:

- one originating in Greece and Egypt, which he characterizes as anti-empirical, proof-oriented, and explicitly religious, and
- another originating in India and Arabia, characterized as pro-empirical, calculation-oriented, and focused on practical objectives.

Raju also makes clear that mathematics is, far from being universal, a cultural construction, influenced by culturally specific philosophies, worldviews (and, indeed, religious doctrines). For example, European mathematics is based on two-valued logic that is just one of the possible logics. Accordingly, one aspect of ethnomathematics is the construction of a counter-narrative valorizing multicultural contributions, an aspect emphasized in the key collection compiled by Powell and Frankenstein (1997).

Furthermore, some mathematicians and other scholars argue that deliberate attention to epistemological diversity, of which Navajo concepts of space and time (Pinxten et al., 1983) provide a good example, could enrich the future development of academic mathematics.

Ethnomathematics and the politics of knowledge

Ethnomathematics undoubtedly has strong political implications. As D'Ambrosio has pointed out, colonialism grew in a symbiotic relationship with modern science, in particular mathematics and technology. Many scholars, such as Zaslavsky (1973), have documented the cultural violence done to the colonized included suppression of mathematical knowledge and practices and the imposition of those of the colonizers. Even in "liberated" countries, the effects of colonization persist, including colonization of the mind, and cultural violence continues against indigenous groups within countries in the Americas, Australasia, and elsewhere.

In a seminal paper, Bishop (1990, p. 51) declared that:

> [Mathematics] had, in colonial times, and for most people, it continues to have today, the status of a culturally neutral phenomenon in the otherwise turbulent waters of education and imperialism. This article challenges that myth, and places what many now call "Western mathematics" in its rightful position in the arguments – namely, as one of the most powerful weapons in the imposition of western culture.

Urton (2009, p. 27) commented that the title of Bishop's paper "must surely be one of the most provocative in the recent literature concerning the history of mathematics and the nature and status of mathematical practice." Illustrating Bishop's argument, Urton provided a very detailed analysis in relation to the European conquest of the New World, specifically documenting the imposition of European accounting methods on peoples of South America, that displaced the highly-developed culturally embedded systems already in place there.

As the counter-narrative gains traction, a fundamental tension arises when efforts are made to honor diversity within mathematics curricula. Barton (2006, pp. 167-168) pinpointed the dilemma of what/how to teach mathematics to indigenous groups while maintaining their cultural identity and the integrity of their mathematical practices. This dilemma arises in the context of global rhetoric proclaiming that learning of advanced mathematics by all students is vital to economic competitiveness. The resulting tensions parallel those caused by the increasing use of English as a world language at the expense of linguistic diversity.

Mathematics as a multicultural school subject

Even among critical and multicultural educators, mathematics is typically regarded as independent of culture; consequently, the need for culturally responsive teaching of mathematics is insufficiently acknowledged. Greer, Mukhopadhyay, Nelson-Barber and Powell (2009) present the counterargument that mathematics merits a central role in multicultural education, and have assembled research and accounts of practice to support teachers and others pursuing culturally responsive pedagogy for mathematics.

Countering the Eurocentric narrative of the history of academic mathematics is a matter of equity in relation to individual and collective cultural identity and agency. Its importance is obvious in countries that were colonized and remain intellectually colonized, but it is also vital, for very different reasons, for the people of the colonizing countries. Increasingly across the world, students are from multicultural and hybridized backgrounds, which deserve to be valorized in relation to mathematics as for any other cultural activity.

There is considerable debate about the propriety of taking what can be construed as mathematics within a cultural practice and adapting it for the classroom, shorn of its original context. Pinxten and Francois (2011) turn the question around by asking what school mathematics education offers children already well adapted to their environments. A balanced approach combines traditional exposure to formal mathematics with more relevance for students' lives, including acknowledgement of diversity of mathematical practices from their backgrounds. Lipka (2009) and his colleagues, working among the Yup'ik of Alaska over more that 25 years, exemplify this spirit in the curriculum project *Math in a Cultural Context* (http://www.uaf.edu/mcc/). (See also *International Study Group of Ethnomathematics* (http://isgem.rpi.edu/) and the *Ethnomathematics Digital Library* (http://www.ethnomath.org) that continually update their collections of ethnomathematics curricular material). Lipka is currently beginning a project on curriculum development, that will attempt to relate, in an original synthesis, traditional knowledge and practices of the Yup'ik in Alaska with theoretical positions in mathematics education, specifically in terms of measurement and proportionality.

However, despite growing interest worldwide in ethnomathematics as a research domain, corresponding curriculum and professional development – in the USA and Europe, at least, remain limited (in some countries, notably Brazil, there has been more progress). Besides long term research projects in a community that have been successful in generating a multi-grade curricula, *Math in a Cultural Context*, there also have been design experiments based on small-scale curriculum development (e.g., Adam, 2004). A question automatically arises as to who is the curriculum for? If the curriculum is designed based on a small community's practice, which is relatively intact, should it be then localized and shared only within the particular community, or shared in a globalized sense? The act of localizing curriculum as a cultural product tends to be synonymous to ghettoizing it, a prospect has been strongly critiqued by Vithal and Skovsmose (1997). A more acceptable solution arises out of situating the local cultural curriculum within the framework of global curricula. With Sinha (2007), we infer that a dialogue between the local and a global mathematical practice within the context of a classroom not only strengthens cross-cultural understanding but also legitimizes ethnomathematics as a school subject.

The principles that should guide bridging between ethnomathematics and school mathematics remain undertheorized. It is essential to consider diversity of the circumstances in which the teaching is situated, and the forms of bridging should be differentiated accordingly. For example, the relatively culturally homogenous nature of the schools with whom Lipka works makes it possible to incorporate traditional Yu'pik knowledge. In a very different setting, Gutstein (2012) works with Chicago students on mathematics relating to generative themes (following Freire) that reflect the sociopolitical realities of their lives – which could, indeed, be considered a form of ethnomathematics. But what might be appropriate for a school with cultural diversity, or a school in an affluent white area? Irrespective of the nature of the school population, we suggest as a minimum that the curriculum should include the ethnomathematical perspective of mathematics as a pancultural human activity, illustrated by appropriate examples, together with discussion of the social history of mathematics, the aims of mathematics education, the uses to which mathematics is put and the nature of the mathematical modeling which increasingly frames our world.

Final comment

The hegemony of mathematics bears striking parallels to the hegemony of English in much of the world; both are reflections of the Freirean quotation which we began by adapting, and of a fundamental fault-line between those who promote global Westernization, and those who value all kinds of diversity. Given the supremacist position maintained by many mathematicians and others who regard abstract mathematics as the crowning achievement of the human intellect, and school mathematics as merely the transmission of its products, the development of a pancultural and humanist view of mathematics, and a corresponding approach to the teaching and applications of mathematics, form an essential front in that struggle.

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Towards an Understanding of Socioscientific Issues as Means to Achieve Critical Scientific Literacy

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In this paper, we make a case for fostering critical scientific literacy (critical SL) using socioscientific issues (SSIs) for students in the 14-20 age group at school and undergraduate level in India. To explicate the idea of how SSIs can serve as pedagogic resource to foster critical scientific literacy, we identify five SSIs related to controversial medical technologies from the Indian media and discuss these issues in terms of an elaborate theoretical framework proposed by Levinson (2006). Finally, we explore the possibilities of whether the Indian educational curriculum has space to accommodate SSIs by critically examining curricular documents at the school and the undergraduate level for the vision of scientific literacy and science-technology-society education that they advocate.

Critical Scientific Literacy

The term Scientific Literacy (SL) is a concept used to 'express what should constitute science education for all students' (Roberts, 2007). The term is contested politically and intellectually and multiple meanings have been attributed to it. Douglas Roberts (2007), in an extensive review devoted to discussing the meanings of SL identifies two positions that have 'come to represent the extremes on a continuum'. He terms them vision-I and vision-II. Vision I represents a view of SL that emphasizes the "cannon of orthodox science"- "products and processes of science itself" in the curriculum. Vision II advocates SL "through situations with a scientific component"- situations students are likely to encounter as citizens (Roberts, 2007). Roberts points out that "considerations other than science" are also emphasised in this vision of scientific literacy. In the vision I-vision II continuum, we position ourselves at the vision II end and advocate a critical scientific literacy. The concept of a critical scientific literacy is not new. Several science educators (Roth & Désaultels, 2002; Hodson, 2003) have advocated it. Weinstein (2008) defines critical scientific literacy as,

> " a certain scholarly and activist tradition rooted in dialogues between Marxism, Antiracism, Feminism, Queer Politics, Liberation Theology, and anti-colonialism—for starters—but also to a prior tradition both within science communities as well as "lay" spheres challenging science's embeddedness within the militarism and capitalism".

Critical SL advocates like Hodson (2003) envision a politicised science curriculum which enables students to understand that science and technology-related decisions are taken in accordance with particular interests of certain groups and are justified by certain values often "prejudicial to the needs of the poor and powerless". In effect, they advocate a conflict view of science education that seeks to question power relations and foster social justice concerns in the students. This vision of scientific literacy is shared by educators advocating feminist pedagogy (Mayberry, 1998) and Freirian science pedagogy (Santos, 2009). Santos (2009) illustrates what a curriculum devoted to critical science education would look like, by using the example of garbage disposal. While a conventional curriculum may focus on topics like chemical constituents of garbage and separation methods during recycling, a critical science education curriculum would primarily be concerned with the humanistic dimensions of garbage disposal like why there are people living in landfills and where they come from.

The importance of critical scientific literacy in developing countries has been stressed by some educators. (Kyle, 1999), in an article devoted to challenging first world hegemony in defining science education goals emphasises the need for social justice concerns that revolve around contextually relevant science-technology and society issues in developing countries.

Socioscientific issues (SSI) and critical science education

One way to foster the kind of scientific literacy envisaged in the previous sections is to engage students in SSI. Hodson (2003) argues that politicization of science education can be achieved by exposing students to real-world issues that have a science, technological or environmental dimension. SSI are "social dilemmas with conceptual or technological links to science" (Sadler, 2004) These are typically ill-structured, real world issues that are controversial in nature. The need to introduce SSI in the school and undergraduate curricula has been recognized by the international science education community as well as national curriculum documents in several countries (Zeidler & Keefer, 2003); (Hughes, 2000).

Different epistemological frameworks of understanding the science-society interface inform how different researchers understand the issue of negotiation of SSI. Levinson (2007) discusses these frameworks on the basis of how technocratic they are. Technocratic frameworks of understanding the science-society interface stress the importance of canonical scientific knowledge in negotiating the issue and see scientific experts as solely capable of arbitrating on it. In non-technocratic frameworks of science-society interface, the central role of science in resolving the controversy is not privileged and the science needed to negotiate the issue is seen as tentative and uncertain. Scientific knowledge may also be critiqued and challenged in this model. Sources of knowledge that resolve the controversy are seen to emerge from the needs of the participant and is interdisciplinary. Anecdotal evidence, local knowledge and socio-cultural world-views are valued. As critical SL advocates, we adhere to a non-technocratic framework of understanding the science-society interface.

Technology related SSI

Derek Hodson (2003) highlights the importance of using problems and issues related to technology in fostering critical scientific literacy. According to him, technology being "all pervasive" in the western world, the values surrounding them are constantly discussed in the print and visual media. In an article devoted to discussing science, technology and values, Allchin (1999) discusses how technologies can either raise new ethical and social dilemmas based on pre-existing values or challenge it more directly. He illustrates with examples of how technologies like hemodialysis and organ transplantation technology sustain the value of preservation of life or health but raise new values on equitability of access while technologies like the new reproductive technologies challenge values more directly by complicating the concept of parentage.

Hodson (2003) argues that it is therefore easier to see how socio-cultural context impacts technology and vice-versa than it is for science but he also underscores the fact that using issues related to technology "is not an argument against teaching science; rather, it is an argument for teaching the science that informs an understanding of everyday technological problems and may assist students in reaching tentative solutions". He points out that a politicised science curriculum rejects the notion of technological determinism and students should be empowered to make choices on what technologies they will or will not use.

Fostering Critical Scientific Literacy Through SSI` Surrounding Controversial Medical Technologies

In this section, we identify five topical SSI in the Indian media which can be used with students of the 14-20 age group. These issues are such that they raise social justice concerns, value concerns and may require the use of scientific evidence for resolution. Some of these issues also raise questions on the validity of scientific perspective. Students can bring in personal experiences and alternative world-views to bear upon the issue.

All the five issues are related to controversial medical technologies. We use a framework suggested by Levinson (2006) to unpack these issues which can be examined at multiple levels. This framework is particularly useful because it is based on a non-technocratic model of understanding SSI and legitimates the role of different sources of knowledge in negotiating the issue. (Levinson, 2006) unravels the epistemological nature of SSIs and is perhaps one of the few frameworks that exist in science education literature that delves into this aspect. One strand of this frame-work that is relevant to our discussion is the detailed profiling of SSIs in terms of the Levels of reasonable disagreement (LoD) which makes explicit what is it at stake in a SSI in terms of evidence, values and world-views.

He discusses 9 levels of disagreement from which SSI can be examined. The direct role of evidence in resolution of the issue diminishes as we move from level 1 to level 9. Concomitantly, other aspects like difference between ethical premises, view-points due to personal experiences, indeterminacy of concepts and differences in world-views become the sources of contention than evidence. It must be noted that evidence may play a role in negotiation of issues at all these levels, but its necessity goes down as we move up the levels. This framework enables us to discuss the issues thoroughly at multiple levels. Table 1 is derived from Levinson's framework (2006) on LoD. Five contemporary SSIs related to certain medical technologies and concerns related to evidence, world-views and values in resolving them are discussed in the table.

The issue of paid organ donation involving live organ donors is controversial and has been discussed in the Indian media[1]. It raises questions on access, safety of donors and larger social justice questions of exploiting poverty (Phadke & Anandh, 2002). Scientific evidence on health risks for organ donors may be important on resolving the issue (Goyal, Mehta, Schneiderman, & Sehgal, 2002). Commercial surrogacy[2] raises similar questions on safety of the procedure for surrogate mothers and biological mothers as well as questions on social justice (Shah, 2009). Value positions on whether biological motherhood is such a valuable end in itself may also be debated. Scientific evidence on safety of procedures and success rate of IVF procedures may be important on taking positions on the issue.

The issue on ultrasound technology and disability is structured around a case that happened in India in 2008 - Popularly known as the "Niketa Mehta Case"[3]. This case initiated an almost non-existent debate in public forums on abortion as well as disability rights in the country. The abortion debate has in some sense been over-shadowed by the sex-selection debate in India (Madhiwalla, 2008). Madhiwalla (2008) discusses the complexities of the issue where the woman's right to a free choice on abortion may be challenged from the perspective of disability rights pitting the feminist and disability movements against each other.

Mid-2011, the “Aruna Shanbaug”[4] case opened up a debate on euthanasia of patients in a permanently vegetative state (PVS). Ethical differences on value of life and right to a life free of pain might be a matter to consider while resolving the issue. Scientific knowledge on nature of PVS state and its diagnosis may inform negotiation. A recent case[5] on sex change operation has opened up debate on gender and sexuality in the Indian media. Apart from the rights of the LGBT community to practise sexuality/gender of their choice, there are more fundamental questions on whether alternative expressions of sexuality need to be considered a 'disorders' and the role of science in legitimating this view (Levinson, 2010).

As it can be seen, there is no dearth of SSIs in the Indian media for students to discuss and debate in the classroom. Using Levinson's framework, key dimensions of these controversies can be parsed out and discussions can be initiated at each of the levels. Students can appreciate the complexity of the issues and employ different domains of knowledge in negotiating it. In doing so, they can also learn about the nature, strengths and limitations of each of these domains of knowledge in negotiating the controversy and the role of evidence.

Are We Ready for SSI in the Indian Science Curriculum? Articulating Concerns

To understand the issue of whether the Indian Science curriculum has any scope to deal with SSI in the manner we advocate to use it, we examine the National Focus Group's position paper on the *Teaching of Science* (National Focus Group, 2006) for its vision of scientific literacy and its advocacy for STS education. This position paper informed the National Curriculum Framework 2005 on which recommendations for textbook writing, both at the national and state level have been based. The position paper appears to advocate a vision I scientific literacy with emphasis on the learning products and process of science as evidenced in this statement:

> Facts, principles, theories and their applications to understand various phenomena are at the core of science and the science curriculum must obviously engage the learner with them appropriately (p.11, Position Paper on the Teaching of Science)

According to the position paper, the 'general aims of science education' should be understood in terms of 6 validities- cognitive, content, process, historical, environmental and ethical validities. Cognitive validity requires that the material be age-appropriate and within the developmental level of the child while content and process validities emphasize the need for factually correct content and appropriate training in the methods of the science. Historical validity requires that some history of science be included so that students appreciate how 'concepts evolve with time' and get acquainted with biographies of prominent scientists while environmental validity requires that the student “appreciate” issues at the interface of science technology and society. Ethical validity requires that student develop certain habits of the mind like honesty, freedom from prejudice and objectivity.

1 http://www.wired.com/medtech/health/news/2007/05/india_transplants_main?currentPage=all

2 http://www.nytimes.com/2011/10/05/world/asia/05iht-letter05.html

3 http://www.indiatogether.org/2008/aug/ksh-mtpchoice.htm

4 http://articles.timesofindia.indiatimes.com/2012-05-13/india/31689540_1_surgery-plastic-surgeon-gender

5 http://www.ndtv.com/article/india/aruna-shanbaug-case-supreme-court-rejects-euthanasia-plea-89894

Although a hierarchy in the importance of the validities are not stated, there is an implicit sense that the core emphasis is on content and processes of science.

This becomes obvious as we look at the prescriptions for science education at different levels. At the primary school level, the emphasis is on *environmental studies* which fuses both the science and social sciences. But from class VI onwards, the curriculum prescriptions emphasise content knowledge. At the higher secondary level, STS is relegated to the domain of co-curricular activities as evidenced by this statement,

"...Students should be encouraged to participate in debates and discussions on issues at the interface of science, technology and society. Though these would form an important part of the learning process, they should not be included for formal assessment" (p.16, Position Paper on the Teaching of Science)

Have you heard of test tube babies?

Boojho and Paheli's teacher once told them in the class that in some women oviducts are blocked. These women are unable to bear babies because sperms cannot reach the egg for fertilization. In such cases, doctors collect freshly released egg and sperms and keep them together for a few hours for ***IVF*** or ***in vitro fertilization*** (fertilization outside the body). In case fertilization occurs, the zygote is allowed to develop for about a week and then it is placed in the mother's uterus. Complete development takes place in the uterus and the baby is born like any other baby. Babies born through this technique are called **test-tube babies**. This term is actually misleading because babies cannot grow in test tubes.

Figure 1. Text box from the class VIII NCERT Science Textbook on test tube babies or IVF

Although the position paper acknowledges that the majority of students up to class X are not training to be professional scientists or technologists and that the science curriculum up to class X needs to prepare students to be scientifically literate to "develop awareness" about STS issues, there is no actual discussion on how these issues should be introduced. STS content is also marginalized in NCERT science textbooks. For e.g. Figure1 from the class VIII NCERT Science textbook discusses the technology of "Test tube babies" or IVF. There is no reference to surrogacy, which is an important aspect of IVF procedure around which several social and ethical questions have been raised. Questions regarding the safety and efficacy of the technology are not raised. The text also propagates the patriarchal myth that infertility is a problem of the woman. This manner of presenting controversial technologies is completely at odds with how a curriculum devoted to fostering critical scientific literacy would present it.

The undergraduate curricula in India tends to be highly specialized, emphasizing rigorous training in content knowledge and laboratory/field work in science subjects. The (Yashpal Commitee Report, 2009) emphasizes interdisciplinarity in the curriculum and exposure of science students to courses in humanities and social sciences, but STS as a subject is non-existent in most undergraduate science courses. Students who take up humanities, social sciences and commerce at the undergraduate level cease to engage in science after school. This trend of decreasing emphasis on STS education as we move up levels of education is in sharp contrast to other parts of the world where there is an emphasis on STS education at the secondary school, high school and undergraduate level (Zeidler & Keefer, 2003; Hughes, 2000).

SSI	Level 1/2	Level 3	Level 4	Level 5	Level 6	Level 8	Level 9
Paid organ donation through living donors	-Health risks for the donor -How is paid organ donation working out in other countries	Concerns related affordability to all and access if it is legalized	Is it ethical to use the poor's need for money to get them to sell organs?	Are the donors making a 'choice' to sell their organs? Is the choice free if it is motivated by poverty?	organ donors health at stake even if people are dying due to lack of availability of organs		Some people might be against commodification of organs
Sex change operations for transexual individuals	Medical risks associated with surgeries for transsexual adults		Right to belong to the gender of one's choice	Transsexualism- a lifestyle choice or a disorder?			Transsexualism is considered by some to be against the laws of nature
Ultrasound technology and its use in diagnosing disabilities	-Nature of disability: Lifespan, morbidity -Options available to accommodate the disabled (special schools, institutions other extant social welfare measures)	Role of the state and family in taking care of disabled patients	-Sanctity of life versus right to life free from suffering -Slippery slope question of whether the technology should be used against minor disabilities	Questions on interpretation of "Rights"- 'Right' to life or 'Right' to life free from suffering		People who have a disabled family member may have strong positions on the issue	A person could articulate a pro-life stand on account of religious/ cultural world-views
IVF technology and Commercial surrogacy	-Health risks for surrogate mother -success rate of IVF procedure -Health risks for biological mother	Concerns related to affordability to all and access	-Adoption versus Biological motherhood -Are poor women going to be exploited?	-What constitutes 'parenthood'? Does lending genetic material amount to parenthood? What about the role of the surrogate mother as a parent? -Are the surrogates making a 'choice' to rent their wombs?	Surrogate mother's health compromised even if infertile couple gets to have their own baby	An adopted person may have strong positions on the issue	A person might view the practice of commercial surrogacy as equivalent to prostitution and may object to it
Euthanasia of PVS patients	-Are PVS patients capable of thoughts? -How long do they survive? -What life support equipment are needed to support them?	Role of the state and family in taking care of PVS patients	Sanctity of life versus life free of pain	Questions on interpretation of "Rights"- 'Right' to life or 'Right' to a life free of suffering	Are PVS patients 'suffering'? (how do we interpret this when the patient is incapable of self-expression)	A person who has seen a close friend /family member suffering from comma/PVS state may construe the issue differently	A person could articulate a pro-life stand on account of religious/cultural world-views

Table 1. Description of SSI based on Levinson 's framework (2006)

Description of the levels in Table 1 (As discussed in Levinson, 2006):

Level 1- "Where insufficient evidence is as yet not available to settle a matter, but where such evidence could in principle be forthcoming at some point"

Level 2- "Where evidence relevant to settling a matter is conflicting, complex and difficult to assess"

Level 3- "Where the range of criteria relevant for judging a matter are agreed, but the relevant weight to be given to different criteria in a given decision is disputed"

Level 4- "Where a range of cherished goods cannot simultaneously be realised, and where there is a lack of a clear answer about the grounds on which priorities can be set and adjustments made"

Level 5- "Where the range of criteria relevant for judging a matter are broadly agreed, but there is dispute about the proper interpretation of a criterion or criteria, given the indeterminacy of many concepts"

Level 6- "Where there are different kinds of normative consideration of different force on both sides of an issue, and it is hard to make an overall judgement"

Level 7-" where there is disagreement about criteria relevant for judgement" (According to Levinson(2006), this category can be subsumed under level 9. Hence it is not discussed in the table above)

Level 8- "Where the differing 'total experiences' of people in the course of their lives shapes their judgements in divergent ways"

Level 9- "Where there is no agreement about whole frameworks of understanding relevant for judgement"

Concluding Remarks

We believe that there is a need to introduce SSI based instruction from the secondary school up to undergraduate level. At the school level, whether they should be introduced in the science curriculum or in the social science curriculum will need to be deliberated on. There could be integrated themes that cut across both the subjects involving teachers in cross-disciplinary collaboration. This would perhaps help teachers deal with the issue of communicating the complexity inherent in these issues. SSI based courses can also be introduced at the undergraduate level which could be open to both science and non-science students. This will enable non-science students to have a continuing engagement with science in a manner meaningful and relevant to them.

The authors of this paper are currently engaged in carrying out studies of how students in the 14-20 age group bring to bear different sources of knowledge in understanding the issues discussed in the paper. These studies could shed light on how curriculum material and classroom discussions can be structured to help students negotiate SSI and develop their sensitivity to social justice questions related to science and technology.

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Students with Disabilities and Their Aspirations in Science

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For a democratic and egalitarian society, education needs to be inclusive so that equal opportunities are made available to all students. However it has been found that only a few students with disabilities get enrolled in higher levels of education (NCPEDP, 2005). One of the reason behind this may be the present state of education which does not take into account the aspirations of students with disabilities (SWD). This paper reports on a study of the aspirations in science of 30 SWD students studying in classes VI to X in 6 different schools. The study is important for science education as it throws light on the aspirations of SWD and suggests ways to make science education more inclusive.

Introduction

For a democratic and egalitarian society education needs to be inclusive so as to provide equal opportunities to all students. According to UNESCO (1994), regular schools with an inclusive orientation are most effective in combating discriminatory attitudes, building an inclusive society and achieving 'education for all'. Research studies have demonstrated the effectiveness of inclusion in education practice, the positive effects on the educational outcomes of children with disabilities in inclusive settings (Katz & Mirenda, 2002) and the lack of any significant difference in the development of children with special needs in inclusive and special settings (Lal, 2005).

The term 'inclusion' in education is "*a philosophical position as well as an arrangement of institutional facilities and processes. This is to ensure access to and conditions of success in education for everybody, including those in the margins, either with learning difficulties because of physical or mental disabilities or because of their social position. The aim is to create an integrated school setting, providing equal opportunities to children with special abilities, varied social backgrounds and diverse learning needs*"- NCTE (2010 pp.13). But, it has been found through surveys that in India only a few students with disabilities get enrolled for higher education (Tables 1 & 2).

Category of disabled	**Number**	**Source**
In school going age	3430000	MHA (2001)
Children with disability having access to education with appropriate support	4% of the above	MSJE (2010)
Disabled youth in age range of attending Universities	3160000	NCPEDP (2005)
Percentage of disabled youth in Universities	1.2% of the above	NCPEDP (2005)

Table 1. Status of education of persons with disabilities in India

Students with Disabilities in Universities	**No of Universities**
Univ. having students with orthopaedic disabilities	1203
Univ. having students with visual impairments	311
Univ. having students with hearing impairments	38
Univ. having students with mental disabilities	22
Number of Universities with no SWD	38 (including TIFR)
Number of Universities not following 3% reservation for SWD	24 (including TIFR)

Table 2. Universities and education of students with disability (SWD), Source- NCPEDP, 2005

Aspirations

The term “aspirations” has several different meanings and for the purpose of this study it needs clarification. Ball and Wiley, (2005) state that aspirations of children are “a reflection of what they wish to become and subsequently guide a number of factors that impact what they will eventually do in life.” The importance of aspirations is highlighted by Sherwood (1989), who associates aspiration with goals and states that aspirations develop a will in students to “invest time, effort or money to attain a goal”. According to Quaglia and Cobb (1996), the term aspiration has the following meanings: goals, expectations, dreams, intentions and performance motivation. For the purpose of this study the meanings of the term that have been accepted are: goals, expectations and intentions. To initiate an inclusive transformation in science education, this study tries to explore the aspirations in science of SWD and also their perceptions of science, science education and inclusion in science education.

Tools and administration

To explore aspirations of students with disabilities in science, a questionnaire was developed which was based on the following research questions: How do students with disabilities (SWD) perceive science; do the careers they wish to pursue involve science; what careers do they prefer to pursue in science; what do they expect to learn in science; what difficulties do they face in learning science; what changes do they suggest in science education; and, what are their attitudes towards inclusion in science. The tool was validated by experts in science education and language and was pilot tested with 6 SWD. The final sample consisted of 30 students from 6 schools, and their disabilities were noted from the school records. Each student was coded on the basis of the following information: school, gender, standard, age, and type of disability. The tool was administered in the school premises and in groups except for the visually disabled. The details of the sample with codes is provided in Table 3.

Code of school	Gender	No. of students in class & Age	Types of disabilities
1. Government senior secondary school for girls	3 Girls	(3) VI std, (11, 12 & 14 yrs)	1 LV (Low vision) 1 OH (Orthopaedic disability) 1 SLD (Specific learning disability)
2. Government senior secondary schools for boys	11 Boys	(9) VI std (11 to 15 yrs) (2) X- std (18 yrs)	4 SLD (Specific learning disability) 1 CD (Cognitive disability) 1 Dwarfness 1 LMC (Lack of motor control) 3 OH (Orthopaedic disability) 1 LV (Low vision)
3. Inclusive school	7 Boys	(7) VI std, 11, 12, 14 to 17 yrs	4 OH, (Orthopaedic disability) 2 MD (Multiple disabilities) 1 VI (Visual Impairment)
	5 Girls	(5) VI std, 13 to 15 yrs	3 OH (Orthopaedic disability) 1 HI (Hearing Impairment) 1 HI&SI (Hearing &speech impairment)
4. Special schools for students with visual impairments	4 Boys	(3) VI- std, 15 to 17 yrs (1) X- std, 16 yrs	4 VI (Visual Impairment)

Table 3. Characteristics of the sample

Findings

What is science?

More than half the students (17) said that s*cience is an accumulated and systematised body of knowledge.* Six students stated that s*cience is a creator of technological product,* while for 3 students s*cience is a scientific* *method of investigation.* For the student with Dwarfism, s*cience is a transcendental experience,* while a girl with orthopaedic disability (School1) felt that s*cience is something entertaining.* According to a boy with multiple disabilities from the inclusive school s*cience was magic,* for a boy with specific learning disability *science is a very good thing,* while another boy with specific learning difficulties from the same school equated *science* with a text book.

Science as a school subject

Of the given options, most of the students (28/30) stated that science was *very important* or *important,* while only 2 students (School3, bOH, bMD) felt that science is *absolutely unimportant.* It is interesting that one of these students (OH) had reported that science is a creator of technological products, while the other had perceived science as magic. Majority of the students (28/30) also felt that science is *very interesting* or *interesting*, while only one student (School2, bCD) found science *boring*, while another student (School4, bVI) stated that science was *somewhat interesting.* Most students (26/30) reported that science is *very useful or useful,* 2 students reported it to be *somewhat useful* (School3 bMD, gHI&SI), only 1 student (School2, bCD) found science to be *useless,* while another (School3 gOH) found science to be *absolutely useless.* Half of the students (16/30) reported that science is *very easy or easy,* 5 students found science to be *somewhat easy*, while 9 students responded that they found science as a subject *difficult* or *very difficult.*

Effect of science on students' lives

Around 13 students said that science *makes life easier,* 7 felt that it *promotes learning experiences* while 2 students felt that it *was an agent of change.* According to 2 students *science takes care of health* while one student (School4, bVI) *felt that it pollutes the environment.* According to a female student from school 3 who was orthopaedically handicapped, *science helps develop healthy eating habits.* A girl from the school with hearing impairment remarked that *science has no effect on their lives*, another girl from school 1 with visual impairment answered that she *did not know*, while a girl from school 3 with hearing and speech impairment did not respond to the question.

Success in school science

In response to the question, how can you get good marks in science, the comments of SWD can be summarised as: b*y reading understanding and writing science, doing hard work, learning question-answers, revision, writing answers correctly, and through mental power*. Most of the students (22/30) affirmed that getting good marks in science means knowing science well, while only 5 students said that getting good marks in science does not necessarily mean that one knows science better (3 students gave unrelated answers). In response to the closed-ended question, what qualities are required to achieve a good understanding of science, most of the students selected the qualities of *experimentation* (27/30), *good memory* (26/30), *truthfulness* (26/30), and *observation* (24/30), *discipline* (22/30), *good understanding of content* (21/30), *analysis* (20/30), *patience* (18/30) and *good understanding of English* (18/30). About half the students selected *repeated practice* (15/30) and *categorisation* (12/30) as necessary for achieving a good understanding of science.

Preferred Career/Job/Profession

To the question what course of higher education would you like to go for, half of the students (16/30) stated that they wish to pursue *science*, 10 wished to pursue *arts* (which refers to humanities in the Indian context), 2 wished to pursue *commerce*, 2 wished to pursue *computer courses*, while 1 wished to pursue a *course of designing*. Interestingly all the 4 students from the special school for students with visual impairments wished to study *languages* (2 Hindi and 2 English) and one among them wished to pursue *English, Political science, History and Science* courses together. The job most preferred by SWD was that of *teacher* (9/30) and interestingly of these 5 were girls. The next preferred jobs were that of a *doctor* (6 students), *engineer* (2 students), *any government job* (2 students), *IAS officer* (2 students and both were from special school) and *cricketer* (2 students and both were OH). When asked what career would they undertake if they were good in science again the most preferred job was that of a teacher (9/30), *scientist* (7), doctor (6), *engineer* (4), *army personnel* (1), *policeman or doctor* (1), *work in a mobile shop* (1), *government job* (1) and *musician* (1).

Learning expectations from science

Some of the students' expectations were directly related to the knowledge domain of science (9 students) for example: *Knowledge of discoveries and discoverers* (School1, gLV), *questions and answers of science* (School1 gSLD, School2, bOH*), easy knowledge* (School2, bSLD, bOH), *becoming a doctor* (School2, bOH), *knowledge of solar system and making machines* (School3, bOH), *knowledge about nutrition* (School3, gOH) and *technological things* (School4, bVI). Some expectations were related to the processes of science (18 students) like: *making drawings and pictures* (School2, two bSLD), *doing practicals in laboratory* (School2 bOH, School3 bOH), *doing projects* (School2 and School3 bOH), *scientific procedures* (School2 bLV, School3 bMD), *doing experiments* (School3, bOH, bMD1, bVI, gHI, gHI&SI, School4, VI), *activities* (School3 two gOH), *inventing and discovering things* (School4, bVI), *learning to become good human beings and assistants of scientists* (School4, bVI). Some learning areas were related to the general education (School2 bSLD, bDW, bLMC) like: *spellings*; *understanding nicely*, *reading, and writing*.

Suggestions for science education

Some suggestions given by students to make science education interesting involved: *making the study of science like a game* (School1, gLV), *making the way of reading interesting* (School1, gSLD), *making science understandable* (School2, bSLD), *studying with concentration* (School2, bSLD), *making jokes* (School2, bSLD), *reading and writing correctly* (School2, bSLD), *through happiness* (School2, bCD1), *understanding and obeying science* (School2 bDW), *reading, writing and sitting silently* (School2, bLMC), *through understandable tasks* (School2, bOH), *making use of technology of science and doing miracles of science* (School2, bOH), *through enjoyment and concentration* (School2, bOH), paying *attention to teacher's words* (School2, bLV), *games* (School3 bOH, three students), *supplementing theory with practicals* (School3, bOH), *experiments* (School3 bMD, two students, and bVI, gOH,), *activities* (School3, gOH, two students), *by understanding what is science and by doing experiments* (School4, VI), *stories along with serious subject matter* (School4 VI), *knowledge about changing World* (School4 VI), *diagrams* (School4 VI).

Knowing the expectations and suggestions of SWD can be helpful in curriculum guidelines for the content, process and the environmental validity of an 'ideal inclusive science curriculum'. Some of the expectations and suggestions made by SWD are acknowledged as principles to be adopted in science curriculum. An important expectation/suggestion put forward by three SWD is the learning of drawings and diagrams in science learning to make it more interesting and effective. In fact drawings and diagrams are an important tool in science for focused observation, understanding and visualisation not only for SWD but for all students. Raised line diagrams have been suggested by Carney, Engbretson, Scammell and Sheppard (2003) for teaching science to students with visual impairments. Conducting experiments, doing activities, practicals and projects were mentioned by 18 of the students as their expectation or suggestions for science education, suggesting the importance of the same for them.

Attitude towards teaching science to SWD

Most of the students (26/30) had a positive attitude towards inclusion of SWD in science. Some of the reasons given were; 2bDW- *"Science has a speciality... science is made for disabled students",* 4bVI- *"If God has snatched the vision then... we can do so much... even... if not scientist... we can do something in future".* However four boys from school 2 (two with SLD, one OH and one LV) stated that science should not be taught to those with disabilities for example, LV said, "*No, because they do not study science properly and are unable to understand alphabets written in science text book*".

Difficulties faced in science

The students were asked what difficulties they faced in learning science as also the difficulties of all students while learning science and those specifically of SWD. The responses are presented in Table 3.

Difficulties / **Questions asked**	**Diff. *you* face while learning science?**	**Diff. faced by *all* students while learning science?**	**Specific diff. faced by SWD while learning science?**
Understanding science	3 students	10 students	6 students
Sensory and cognitive difficulties	4 students	7 students	14 students
Reading and writing	8 students	4 students	4 students
Memorising	4 students	1student	
Answering the questions of science	3 students	1student	
Lack of concentration	1student	1student	
Drawing & visualising diagrams	2 students		2 students
Revision	1student		

Doing practicals	1student		
Lack of laboratory facility	1student		
Lack of knowledge of English	1student		
Difficult words		4 students	
Irrelevant curriculum & lack of text-books		1student	
Disturbance due to treatment			1student
Doing activities that need locomotion or sitting			4 students
Responding through speech			3 students
Do not face difficulty	10 students	2 students	3 students
Unrelated response	1student	2 students	3 students

Table 4. Number of SWD giving responses in particular category, to the questions asked

Conclusions

The study reports the perceptions and aspirations of 30 SWD from classes VI and X of six different schools with respect to science and suggests ways to make science education more inclusive. Most of the SWD have positive attitude towards science, and perceive science as important, interesting and useful. The most commonly held views of SWD about nature of science are "*science is an accumulated and systematised body of knowledge" and "science as a creator of technological products"*.

The SWD in the present study found science difficult due to their inability to understand science and due to some cognitive or sensory disability. The reason for their inability to understand may be derived from the India Science Report (Shukla, 2005), which states that 40% of general students who did not opt science at senior secondary level did so because "the number of students in a class were too many for them to understand what was being taught". Some students also report that very difficult words and inability of students to read and write also cause great difficulty in learning science.

From Table-4, it can be noted that there are some specific difficulties that are faced only by SWD, such as, drawing and visualising diagrams, revision, doing practicals, lack of laboratory facilities, lack of knowledge of English, disturbance due to medical treatment, doing activities that need locomotion or prolonged sitting, and responding verbally. The sample SWD also reported that all students face difficulties in understanding science, due to sensory & cognitive difficulties, difficulties in reading, writing, memorising, answering the questions of science, lack of concentration, difficult words and irrelevant curriculum and lack of text-books. On comparing the general students of +2 level in the India Science Report (2005), where a third said "they did not study science as they did not feel motivated enough", we find that the SWD are generally motivated to study science but, it is due to the stated difficulties that they are unable to opt for science at higher levels. It is also important to note that 8 of the 12 students from the inclusive school responded that they do not face difficulties in learning science indicating better science education facilities for SWD there.

The present study reports that in order to get good marks in science, according to SWD they need: reading, understanding and writing of science, hard work, learning question-answers, revisions, writing answers correctly- all of which are similar to the difficulties that they report they face in science. This may lead to a need of extra 'hard work' for SWD or lower grades in science examinations, thus causing problems in their opting for science at higher levels.

The SWD showed interest in a vast spectrum of interesting areas of science which they wish to explore and learn. It is interesting that the number of students who wish to learn processes of science is almost double to those students wanting to learn different areas of knowledge in science. The suggestions given by students are very important as these suggestions have been given by the very target group which is the focus of various experimentations, seminars, and workshops and for whom various policies of inclusion are being brought forward. Another important point is that the implementation of these suggestions such as focussing on activities, experiments, practicals, projects and drawings and diagrams would make science more interesting, useful and effective not only for SWD but also for all students with diverse learning needs and diverse backgrounds.

A positive finding is that science is the most preferred subject for SWD for higher education (16/30). This is comparable to the 60% of general students at the class six to eight level in the India Science Report (Shukla, 2005), who wanted to pursue some science course at higher level of education. A high value for science is demonstrated by SWD through their preference of science related jobs like, doctors, engineers and scientists. The study is in accordance with Bevins, Brodie & Brodie's (2005), study which reports a contrast between a small number of students from industrialised societies having aspirations to become scientists or technologists and the high value of careers in science and technology for school students from developing countries. But sadly in India only a few SWD get enrolled in courses having science background (refer Tables 1 & 2), and they are almost invisible in science related jobs.

An important finding is the preference of SWD for the profession of teacher. Being a teacher is their choice in both instances- their first choice and also in case of their being good in science. Scientists, doctors and engineers were the second, third and fourth most popular professions respectively. This finding is similar to the choices made by general students of classes VI to XII, as reported in the India Science Report, where the three most preferred professions of students were teacher, doctor and engineer (Shukla, 2005).

Implications and limitations

This study presents how SWD perceive science, their high aspirations and their positive attitude towards science as well as the difficulties faced by them in learning science. The students themselves have reported their areas of interest and suggested ways to make science more interesting, useful and effective. These suggestions have implications for the curriculum developers to help them incorporate these while developing an inclusive science curriculum. These findings indicate that there is a gap between the high aspirations of SWD in science and the meagre status of enrolment of SWD in science courses for higher education and in turn in the jobs requiring science backgrounds. In this study more students from inclusive settings reported not facing difficulties in science this indicates better science education conditions in inclusive settings.

It is important to note that the process of inclusion is not only beneficial to students from diverse abilities and disabilities, but it would also be beneficial to science education as a whole. To bring about meaningful progress in science education we need to incorporate the diverse abilities, backgrounds and experiences of students and teachers.

The study is limited as we have not collected responses of general students from the inclusive and non-inclusive settings, which could be compared with the responses of SWD. The small sample also hinders the comparison of responses between the students from different educational settings, namely general school, inclusive school and special school, and also between students with different disabilities.

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Putting Kolams: Mathematical Thinking in a Women's Art

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Most visitors to Tamil Nadu are struck by the ubiquity of designs made of white quartz dust and/or rice powder newly made each morning on the ground outside of homes. They are called kolams, and are “put” almost exclusively by Hindu, and some Christian, women. Observant mathematicians and math educators are immediately struck by links between kolams and various branches of mathematics that include (but are not limited to) school mathematics or the practical mathematics of everyday life; kolams suggest introductory topics in discrete math, number theory, abstract algebra, sequences, fractals, and computer science alongside those in algebra and arithmetic. Early work connecting kolams with research in mathematics and computer science was conducted by Siromoney, Siromoney, and Krithivasan (1974). In addition, the learning of kolams can be aided by mathematical knowledge and techniques, suggesting that proficiency in kolams might be accompanied by an affinity for mathematics.

In contrast with this outsider's view, there is no doubt that for most Tamils, including the vast majority of the women who put them, kolams are *not* considered to be mathematical objects. This interview-based study examines the relationship between the thinking of the women who put kolams and mathematical thinking. Due to space constraints, a discussion of the cultural context of kolams is not included in this paper. The reader curious about kolams outside of this paper's narrow focus can find more information elsewhere, for example in Layard (1937), Nagarajan (1993), Dohmen (2004), Mall (2007), and Laine (2009).

Motivation and Research Question

The question of what it means to think mathematically has been revisited many times by many thinkers in many fields. This paper is a very early report on an ongoing empirical study conducted in the spirit of grounded theory and, as such, cannot hope to answer that question in general.

The larger project does hope to contribute to an understanding of whether any part of mathematical thinking (as understood by mathematicians and math educators) has resonance for women involved in a mathematically rich culturally-embedded practice squarely outside of an academic setting, and whether the way these women think about what they do (as opposed to the objects they make) has resonance for mathematicians or math educators. Such an understanding may have broader implications, perhaps for mathematicians who wish to be effective instructors to non-mathematicians and who might struggle with what it means to think mathematically outside of the highly technical arena of research. Paulus Gerdes wrote about his encounter with the Angolan sand drawings called sona: “[e]ver since my first personal contact with the sona, I 'felt' – trained in Europe as a research mathematician – that I was dealing with mathematical ideas.” (Gerdes, 2001). Mathematicians who have looked at kolams have a similar reaction. However, for the most part, the voices of the women who make kolams have not been a significant part of the mathematical discussions around them.

This paper is based on the analysis of initial open-ended interviews of over 40 kolam experts and a small number of teachers and mathematicians familiar with kolams. It examines a much simpler question: *To what degree do women who are experts in putting kolams express ideas, demonstrate strategies, and participate in discussions that are recognisably mathematical, as defined either by math educators or mathematicians?*

Tamils who do not themselves put kolams will express admiration for a beautifully put kolam along with the opinion that the main skills involved are hand-eye coordination and memorisation. The initial data indicate that while none of the women spontaneously made conjectures, generalised or proved theorems in ways that look like the final products of research mathematics, kolams occupy a rich space between the purely functional and the purely intellectual, and involve many features of mathematical thought. For many women there is a cultural imperative to put a kolam outside her home everyday, but it is a personal choice and a significant commitment to learn a large number of complex kolams. This is especially true for working women who have little leisure time.

Context

In the ethnomathematics and math education literatures, philosophical and practical questions have arisen both about the view of mathematics as a European creation and about the relationship between research mathematics as it is conducted in universities, the mathematics taught to undergraduates in technical majors, school mathematics as it is taught in K-12, and the mathematics that exists outside of academic settings. Gerdes (2006) and Eglash (1999) highlight the mathematical knowledge that can be gained through exploring traditional design and the process of making patterns by hand. Researchers and educators such as Selin and D'Ambrosio (2000), Ascher (2004), Frankenstein and Powell (1997), and Joseph (2010) influenced views of the history of mathematics and led to the wider use of materials from non-European cultures in math classrooms. While some educators continue to defend the teaching of school mathematics in terms of providing valuable tools for everyday life, others such as Lave (1988), Nunes, Carraher, and Schliemann (1993) and Dowling (1998) have highlighted the disconnect between the math of everyday life and school mathematics. Some, such as Evans and Tsatsaroni (2000) and Lockhart (2009), have also made the case that promoting math as a utilitarian subject hurts the discipline of math. And many in the mathematics education community, such as Driscoll (2007) have been promoting teaching mathematics as "habits of mind" rather than emphasising specific topics.

Methodology

A series of open-ended interviews with kolam experts is underway. Thus far, 49 women have been interviewed. Eight are high-caste (Brahman), approximately two-thirds grew up in villages, 7 still live in villages, and they have between zero years of formal schooling to post-graduate degrees. Most are either housewives or domestic workers, a few are teachers, college students, office workers, and professors. They were all identified as experts through kolam contests, neighbours, family members, employers, or others in the study. The interviews are similar to clinical interviews developed as part of research in math education (Ginsburg, 1981), starting with a simple request to teach the researcher some everyday kolams that the interviewee likes to put, followed up with questions such as "Are any of these kolams alike?" "Can you make another one like this one that is smaller or bigger?" or "Can you finish that kolam in another way?" The women were interviewed for between one and three hours depending on their availability, level of interest and knowledge. The most skilled women could draw (or put in powder) on the order of 50 different kolams from memory in a single hour. Follow-up interviews with the most skilled participants are ongoing.

Where possible, the interviews were conducted either with a video camera, or using a pen that links an audio file to pen-strokes. This allows for the sequence in which different parts of the kolam are drawn, and the facility and speed with which they are drawn, to be part of the data. The interviews were transcribed in the original Tamil and English and then translated into English. Notes about which kolam was being drawn at which points in the interview were added to the transcripts, along with any observations about how it was drawn.

Data Analysis

The initial interviews are being coded to create more focused research questions. A set of structured follow-up interviews based on this analysis are being piloted. The initial analysis is inspired in part by Lobato (2003), making a distinction between an actor-oriented analysis and an observer-oriented analysis.

The first approach is an attempt to understand as clearly as possible how the creators think. In this analysis, the focus is on language the women use, the manner in which they put the kolams, their discussions about kolams with relatives and neighbours, and so on. This is not without pitfalls: the mere fact of a researcher paying such close attention to something they are not used to thinking of as important has an impact. Some of the interviewees say it is the first time they have thought about one or more of the questions.

The second approach is to analyse the kolams from the perspective of a university-trained mathematician. The researcher has been learning to draw kolams from notebooks, videos and photographs, keeping track of when she is or is not consciously using mathematics to learn and analyse them. Interviews with math teachers and other mathematicians will eventually inform this part of the analysis.

Preliminary Observations

During the initial round of data collection and analysis some potentially interesting lines of inquiry have surfaced. Four of these are discussed below in detail; and some others are briefly noted in the final section. For the sake of brevity, the issues discussed here are limited to a type of kolam called *kambi* kolam. An array of dots (*pulli*) is placed on the ground, and then one or more curves (*kambi)* are put around the dots according to fairly strict, but unarticulated, rules. All but a handful of women claimed that these kolams provided the greatest mental challenge, and mathematicians familiar with kolams find the richest possibilities in them.

Structure: The Importance of the Pulli

Those who are not practitioners of kolams, whether from Tamil Nadu or from elsewhere, often miss the importance of the array of *pulli*, focusing instead on the beauty and complexity of the designs formed by the *kambi.* However, for the women who make them, the *pulli*, and the structure they provide, are paramount. This importance reveals itself in several ways.

One participant explained "if the dots aren't right, the kolam won't come," and this sentiment was repeated in one form or another by almost everyone interviewed. In fact, often when a mistake is made while putting a complex kolam, the woman will say "there is a mistake in the dots," whether or not that is the case. Only once (in over 50 such incidents analysed so far) did a woman go on to correct the dots and finish the kolam; usually a kolam was abandoned if the woman perceived the dots to be incorrect.

In another context, when asked whether there are other kolams similar to those a woman has put in the researcher's notebook, the reply was often "yes, there is another one, but I don't remember the dots." This was often followed by a refusal to try to recreate the kolam.

The dot arrays also loom large in the responses of these experts when asked about which kolams are alike. It is the first (and often only) reason given for saying that two kolams are *not* alike. The converse does not hold: it is not enough for two kolams to have the same dot array to be considered alike. In such a case, often she will say "the *pulli* are the same, but the models are different." (The English word "model" is commonly used, and not easy to define.)

For many mathematicians, the array of dots can be viewed as a problem for which a particular kolam is a solution. For example: "Is it possible to put a single *kambi* kolam with 90-degree rotational symmetry starting with a 5 by 5 array of dots?" Though none of the women expressed the challenge in such an explicit way, an unexpected outcome from when the researcher gave ST some pages with pre-printed dot arrays is suggestive. ST did not attend school and is not accustomed to pencil and paper. She had trouble drawing straight dots in the notebook which was adding to her difficulties in drawing the *kambi*. Once given the pre-printed sheets, she expressed delight, and started to put kolams she had never put before. She said that the interview had "brought something out of her" and expressed sudden enthusiasm for a follow-up interview despite her exhausting work schedule as a live-in maid. After that day, giving out pre-printed dot arrays towards the end became part of some open-ended interviews, and is part of the structured interview being piloted.

Classification: Tilings and Sequences

During the interviews, the researcher often asked whether any kolams on given pages were the same, or whether the interviewee could put another kolam of the same type as one already in the notebook. The questions come up naturally in the context of how to make a kolam bigger for the Tamil month of *Margazhi,* when it is important to put large kolams each day. These simple questions gave insight into how women classify kolams.

There are two distinct approaches that came up regularly. The first is to repeat a basic unit in a kind of tiling. For the women who expressed the most enthusiasm for that approach, the structure of the tiling was clearly separated from the unit used. For example, SK put nine different kolams starting with a 5 by 5 square array of dots, and said that any one of them could be expanded to fill as big a space as desired, with the corner dots shared by touching tiles. She showed the researcher one such example, using what she (and the researcher) considered to be the simplest basic unit: "This one is easiest, so madam can learn it."

Another common practice of enlarging kolams creates single larger units rather than tiling the same small unit. One of the simplest such examples is shown below. The figures show three kolams that were usually labeled 4-dot, 8-dot, and 12-dot versions of the same "model". (The numbers refer to the number of dots in the longest row.) During a gathering with another mathematician, a group of math teachers and a group of cleaners at a school, one of the cleaners put the 24-dot version in powder on the ground. After she was finished, the researcher asked her if there was a smaller kolam of the same type. She put the 4-dot version, and claimed it was the smallest. Both mathematicians were surprised by this answer, having decided beforehand that the 8-dot version "ought to be" the smallest example of that type. The mathematicians were assuming that the smallest kolam should carry necessary information

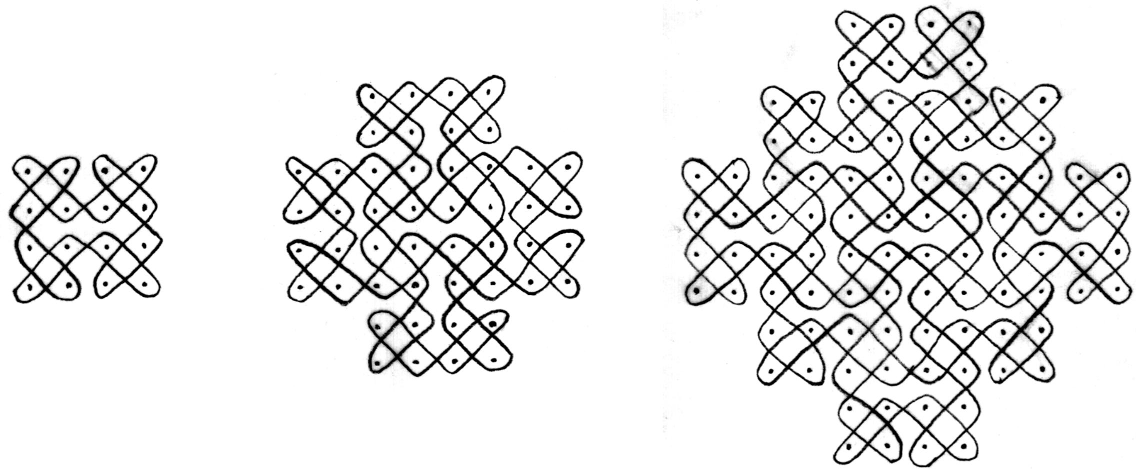

Figure 1. 4-dot version, 8-dot version and 12-dot version

about how to "go onto the next size." At first glance the 4-dot version suggested the next in the sequence should be a larger square, rather than having the stepping stone array of the other kolams in the sequence. Upon reflection, the researcher decided that perhaps for the woman who put the 4-dot version, the smallest kolam was not necessarily the generator of the larger versions; rather she appeared to be following an algorithm for going down from 24 to 20 and so on down to the 4-dot version.

Since the women do not care about creating a rigorous classification scheme, as a mathematician might, their classifications are not consistent across types of kolams. There are examples of sequences of kolams where the smallest exemplar differs from the rest and examples of sequences in which they do not. In some "models" the smallest may even have a different symmetry group from the rest of the sequence, even though the symmetry group is the same for all larger elements of the sequence.

Mathematical Dispositions

Exploring the question of when larger kolams are the same as smaller kolams led to an extended interaction with a group women in a village. The 9-dot version of the kolam below is fairly common; the 15-dot version much less so, and to date no woman in the study has drawn one larger than 15. NT's attempt inspired the researcher to make what she thought ought to be the next three in the sequence, with 21, 27, and 33 dots. To do this, she used a kind of "dual" that shows the structure of the kolam and acts as a guide, like that traced in the right hand drawing on the previous page. After KA tried to draw a 21-dot version that had 17 closed curves instead of 1, and three other women in the village all tried, unsuccessfully, to draw a 21-dot version with only 1 curve, the researcher showed her attempts and asked them if they were "correct." The women discussed the different versions at length and ultimately decided that the researcher's version was correct. The discussion was taken very seriously by all three women, and the decision, once reached, was accepted by all.

Although this was an exceptional sequence of events, several features of the discussion were seen in other interviews. In particular, the idea that some kolams are correct and others are not, while not universal, is common. And the persistence with which they approach often difficult tasks is also common, with women often insisting on fixing difficult kolams, despite sometimes impatient husbands and children waiting for dinner to be cooked. Many of the women said that they preferred one-curve kolams to the (often easier) multi-curve kolams, and preferred to put the one-curve kolams all at once rather than in pieces, because of the feeling of satisfaction gained from succeeding in a challenging task.

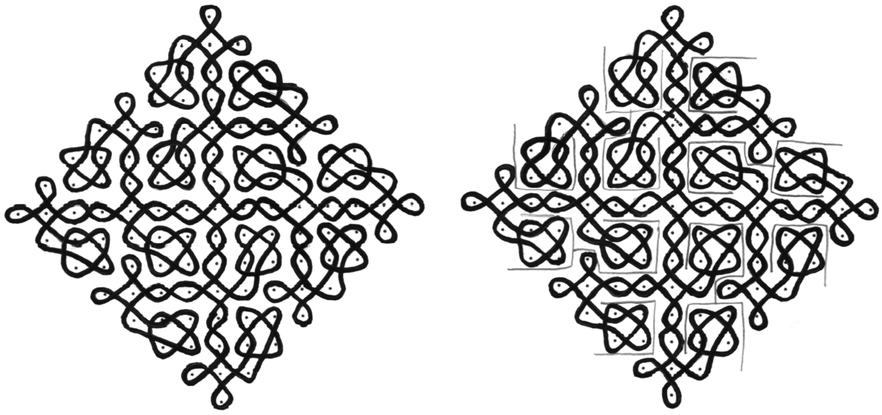

Figure 2. 15-dot kolam and 15-dot kolam with tracing of "dual"

In addition, during the process of building larger kolams out of smaller units some women used a strategy to join together modules that this researcher and several other mathematicians independently "discovered" as a way to create variations and prove some simple theorems.

Doing vs. Saying

One of the methodological issues that needs to be grappled with in this study is how to balance the evidence from what women do with what women say. Understandably, most are much more comfortable drawing kolams than they are talking about them, and this discomfort is evident in the relatively sparse language they use. For example, when a woman is trying to remember a complex kolam that she has not put since *Margazhi*, there is strong evidence that she is aware of the symmetry group. Of over 1000 kolams put in the researcher's notebook, and over 1500 photographed in situ, only a handful show what the researcher identified as mistakes in symmetries, and almost all of those were made during improvisations of complex kolams. Usually, if a half-remembered kolam has four-fold rotational symmetry, a woman will typically start by drawing a motif at one corner until she is not sure how to continue. Then she will repeat that at the other corners before working out how to connect the *kambi* in the middle. If there is mirror symmetry as well as rotational symmetry, she breaks the process down even more: drawing one half of the motif at a corner until she runs of out steam, then drawing the mirror image before moving on as before. Many women acknowledge this as a strategy for recreating kolams, even as they express a preference for putting them as a single curve. ST explained it thus when asked why she was rotating the notebook and putting a kolam in pieces: "I used to be able to put this kolam in one line, but I haven't put it for many years."

However, none of the women distinguish linguistically between rotations and reflections, using general terms such as "it's the same on both sides" for either situation. An analysis that focuses on language alone may miss something: suggesting a potential confusion or lack of knowledge that their actions refute. The structured interviews should shed light on the specific question about symmetry groups, but the larger methodological issue remains.

A particularly dramatic example of this issue arose in a follow-up interview with VS, a skilled and versatile practitioner. Several other women appeared to favour a particular structure. One of the simplest such examples is given here in two forms, a finished kolam on the left, decomposed into three separate curves on the right. Note that the lightly-drawn curve is identical to the a 90 degree rotation of the dark curve. The dashed curve is needed to finish the kolam, enclosing the remaining dots.

Of the 46 kolams VS drew in her initial interview, only 4 were structured in this way. The researcher asked her how one such was formed, and she pointed out, with no hesitation whatsoever, that there were exactly three curves and that "this curve" (the repeated curve) was on "both sides". When the researcher pointed to another few with that same structure, she again pointed to the rotated curve and said it was on "both sides." At this point, the researcher asked her if she could draw another kolam "like these" and her response was to draw one that had the same dot pattern as the last one discussed, rather than one structured in this fashion. The researcher again pointed to the way the other four were structured, and asked if she thought they were alike in some way. VS agreed they were, but laughed at the idea of discussing it further, saying "we just put the kolams!" She went on to draw a completely unrelated kolam she particularly wanted to show. However, in the hour following this short conversation, almost a quarter of the kolams VS put had this structure. She had not previously demonstrated a particular interest in these types of kolams. Therefore, it is tempting to say that what she did (putting those kolams) is a stronger statement than what she said (that she didn't think about them in this way).

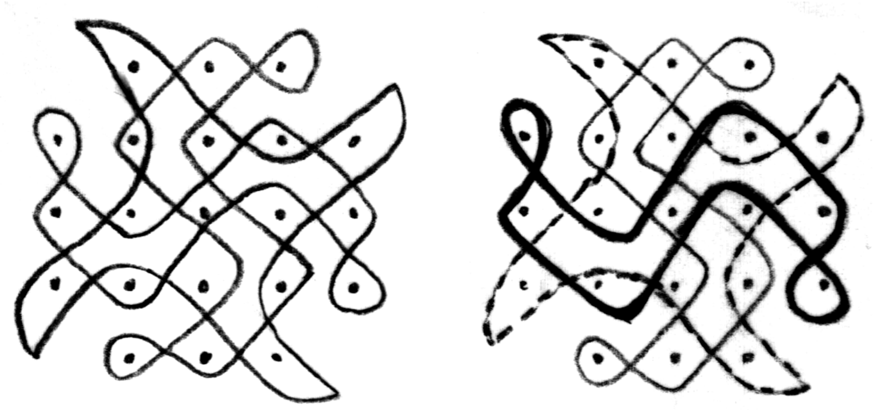

Figure 3.

Continuing Research

The initial interviews also shed light on the differences between how experts and novices classify kolams, awareness the women had about the unarticulated rules of *kambi* kolams, additional strategies for remembering kolams, algebraic thinking involved creating sequences, problem-solving strategies used in creating new kolams, and the disconnect that appears to exist between mathematical thinking displayed in kolam-making and that learned or taught in school. These, along with some of the more speculative ideas discussed in this paper are the focus of ongoing data collection, through structured interviews, observations of groups, and conversations with experts about mathematicians' understanding of kolams. Interviews with math teachers, mathematicians and math students, whether kolam experts or not, will add to an understanding of what it means to look at kolams through mathematical eyes.

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Vigyan Mandir Experiment – The First Mass Scientific Literacy Effort in India

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Vigyan Mandir experiment was one of the earliest mass scientific literacy efforts made by the Indian State. Vigyan Mandirs- temples of knowledge – were to be established in every block or at least in every district, to spread scientific temper and conscientise people. This paper traces the historical evolution of Vigyan Mandirs and their subsequent demise.

Hailed as the first ever institutional effort for "popularising scientific and technical knowledge in rural areas", 'Vigyan Mandir' initiative by the then newly independent Indian state was a unique experiment worthy of examination and recall.

By the beginning of twentieth century, science was being celebrated as the harbinger of material progress through the technologies it engenders. Further, for many radical reformers, science was also a symbol and a potent tool for social and cultural change. Epistemology of science, or what is popularly known as the scientific method, they posited, provides an incessant criticism of all the social evils such as, caste domination, gender discrimination, exploitation and so on. Divided into numerous religions, regions, castes, sub-castes, and languages in the present, unification was sought in the modern nation; New India (Nav Bharat) that was to emerge. Inevitably, such a modern nation had to be inclusive and tolerant and had to be united to survive. Rationality of science, secularism and social justice were the three pillars on which the idea of Nav Bharat was imagined. Thus as Bhikhu Parekh[1] observes, scientific temper, along with concerns like industrialisation, non-alignment, secularism, and national unity became the cornerstones of national ethos of the independent young nation in 1947.

Tormented by the partition and the sectarian violence that ensued, millions were living in abject poverty. Frequently besieged by famines and exploited to hilt by the colonial administration, the independent India saw in science, the solutions to its varied problems. Therefore, two distinct projects – nurturing scientific expertise and instilling scientific temper were undertaken by the young nation. While on one hand, scientific institutions and massive funding for institutions of higher learning were made to nurture scientific expertise, attention was also paid towards cultivating scientific temper.

Thus, unlike scientific expertise, which would be the preserve of a small elite of scientific workers, the project of instilling scientific temper was a call for the diffusion of "science mindedness" throughout the population – cultivating 'scientific temper'. The growth of scientific temper was measured by the extent to which ordinary people were using the methods of science to solve life's problems, including social ones such as the place of women in the society. Clearly, what the above meant was that, science would not just play a role in building scientific expertise, but also it would help reject superstition, prejudice and injustice. Science was to come forward in changing our thoughts and eradicating various social evils, including casteism, extremism and bigotry.

Nehru and science

Nehru's fascination for science was unabashed[2]. He saw the redemption from the evils prevalent in newly liberated Indian state through modern science and technology. In his 'Glimpses of world history' Nehru observes, *"Science does not simply sit down and pray for things to happen, but seeks to find out why things happen. It experiments and tries again and again, and sometimes fails and sometimes succeeds - and so bit by bit it adds to human knowledge. This modern world of ours is very different from the ancient world or the middle ages. This great difference is largely due to science, for the modern world has been made by science."*

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1 Bhikhu Parekh, 'Nehru and the National Philosophy of India', Economic and Political Weekly, Vol 26, No 1 /2 (Jan 5-12, 1991) pp 35-48.

2 See Jawaharlal Nehru on science and society: a collection of his writings and speeches, Nehru Memorial Museum and Library, 1988 for selections of his writings on science.

Hastening to make India modern, Nehru turned to science and technology and his rhetoric is replete with references to modern science. In his often quoted speech at the National Institute of Science, he emphasised, *"It is science alone, that can solve the problems of hunger and poverty, of insanitation and illiteracy, of superstition and deadening of custom and tradition, of vast resources running to waste, or a rich country inhabited by starving poor... Who indeed could afford to ignore science today? At every turn we have to seek its aid... The future belongs to science and those who make friends with science."* Science was seen as the harbinger of social change. Inspired by Nehru, science popularization was considered the duty of welfare state and formed a part of the public policy of Indian state.

Nehru's famed declaration that *"dams are the temples of modern India"* encapsulates the strong pro-science attitude that the Indian state had and it was reflected in the massive amount of state funding provided to scientific research institutes, and the unparalleled status and privileged access accorded to scientists such as the nuclear physicist Homi Bhabha by the state establishments.

In the first five year plan in 1952, a Community Development Programme was initiated to "*bring about social and economic transformation in India's villages."* This centrepiece of Nehruvian policy for the Indian countryside was heavily interventionist. This formed a part of the domain of action of the rapidly proliferating state and other development agencies. Initially the focus was on agriculture and allied areas. However with the 'socialist' turn taken during the second five year plan, modernisation of villages and rural areas were incorporated into the Community Development Programme. Arguing that *"modern economic development calls for a wide diffusion of the scientific temper of mind, a sense of dignity in labour, discipline in service, and a readiness to adopt new techniques and new knowledge to fulfil the needs of the people"* the second five year plan, ushered in by Nehru in 1958 promoted a scheme for setting up of a chain of 'Vigyan Mandirs' (Temples of Science) across the country. The network of 'Vigyan Mandirs' (Temples of Science) dotting the rural areas of the country was expected to replace the unreason of 'religious passions' with the rationality of 'scientific temper'[3].

Vigyan Mandirs –Temples of Knowledge

The Vigyan Mandirs were to "*disseminate scientific information of interest to the rural population*"[4] and were equipped with scientific appliances, films, slide projectors and a library of books. The center was envisaged to "*help and advice villagers on matters vitally concerning their well-being and to educate them on methods of science which would enable them to take greater advantage of the programmes in agriculture, health, sanitation, etc."* A small rural science museum containing specimens of local flora and fauna, minerals, diseased plants, and other objects of scientific interest was to be appended to each of these Vigyan Mandirs. The museum was to be equipped with scientific models showing various scientific phenomena. A rural science club, open to all the people living in the locality was to be organised. The club was envisaged to arrange film shows on subjects connected with plant protection, health, hygiene, sanitation, agriculture, popular science, village industries, etc. The Vigyan Mandir was to serve as a platform for discussions and talks between the experts and the rural people on matters connected to the above problems.

The Vigyan Mandir experiment began as the initiative of Dr S. S. Bhatnagar, then Head of Council of Scientific and Industrial Research in 1953. Perhaps the scheme drew from the ideas of Open Air Science School mooted by the Director of National Botanical Garden Lucknow, Dr T.N Kaul[5] and most likely received patronage of Jawaharlal Nehru, the first Prime Minster of India.

One Vigyan Mandir each, was to dot all the 5000 or so 'development blocks' carved by the newly independent state under its ambitious Community Development Scheme in the first five year plan. By the multi various activities that Vigyan Mandirs were expected to undertake, science consciousness among the people in the rural areas of the country was to be stimulated.

The first Vigyan Mandir was set up at Kapashera near Delhi, under the aegis of CSIR, on August 15, 1953 with then Prime Minster Nehru[6] inaugurating the center. In his speech at the function, Nehru observed that the

3 See Srirupa Roy, Beyond Belief: India and the politics of postcolonial nationalism, Duke University Press, 2007 for a discussion on the role the notion 'scientific temper' played in construction of modern Indian state. Also see Subir Sinha, 'Lineages of the Developmentalist State: Transnationality and Village India, 1900-1965', Comparative Studies in Society and History, vol. 50, no. 1, 2008 for a discussion on the 'development' programmes initiated under Nehru.

4 Second five year Plan, Chp 24 -17, Planning commission

5 Abdur Rahman, Triveni: Science, Democracy and Socialism, Indian Institute of Advanced Study 1977. P.88. also see TN Kaul, Vigyan Mandir- a open air science school Lucknow 1954

"miniature house of science – Vigyan Mandir- would teach- villagers how they could tackle their problems of daily life in a scientific way".

By setting up Vigyan Mandirs, CSIR conceived *"to stimulate science consciousness among the people in rural areas of the country"*. These rural scientific centers were "*to act as centers of dissemination of scientific and technical information"*[7] and *"take the results of the researches to peasants"*[8]. This Vigyan Mandir was the first institutional attempt for popularising scientific and technical knowledge in rural areas of India. This center was designed to assist the villagers in solving their day-to-day problems, particularly those relating to agriculture and health. For instance, it was expected to concern itself with soil and water analysis and the study of human diseases. It was to also help disseminate scientific information and make available the literature and materials for the treatment of plant diseases. If the experiment proved to be successful, it was proposed to extent it to about 5000 blocks.

The task that a Vigyan Mandir was expected to accomplish and the role it was expected to play was far and wide[9].They were to educate the villagers on sanitation, health, hygiene, balanced diet and nutrition, pest and plant diseases, taking into account the resources available in the rural areas. The Vigyan Mandirs were housed in buildings provided by State Governments. Each Vigyan Mandir was under the charge of a Vigyan Mandir Officer, assisted by an Assistant Vigyan Mandir Officer and three scientific assistants. Vigyan Mandirs were to undertake four most important activities; manage a scientific wing consisting of laboratory attached to it, manage a library wing consisting of library and the reading room, maintain the museum wing and look after the function of the rural science centre including science clubs. The laboratory wing was to spread scientific information regarding soil improvement, conservation of soil and soil moisture, water application methods, improved agricultural practices, plant protection, food preservation and so on.

The Vigyan Mandir Officer (VMO) was to identify and gather progressive farmers and mobilize their agency to reach people. In places where no science clubs have been set up, the Vigyan Mandir Officer was expected to persuade teachers to organize them. The VMOs were to participate in the meetings of agencies like youth clubs, community centers and mahila samaj conducted in the blocks where they were located and infuse scientific consciousness and scientific temper. As just two VMOs per block were too small in number to make an impact, trained teachers were to be mobilized as 'intermediates' to create science consciousness amongst the rural people. The VMOs were supposed to undertake water analysis and ascertain it's suitability for consumption and irrigation. They were to be supplied with suitable set of chemicals so that they could undertake tests to check food adulteration.

It was posited that through the laboratory, simple experiments could be performed partly for service purposes but more so in order to make villagers familiar with the techniques of science and to make them realize how science can be of immediate value and significance to their personal lives. To this extent the Vigyan Mandirs were to perform a sort of 'extension service'. However these tests and studies were not merely indented to improve agricultural operation, but were considered an important aspect of generating scientific consciousness. The undertaking of soil sample analysis or simple pathological examinations was to serve more than as a device to advise the people in rural areas. Apart from, aiding diagnostic work, such examinations in the presence of villagers, encouraged their participation in these scientific analyses and was in itself seen to have real educational value.

There were indeed soil and water testing labs and services of these were to be provided by community development projects and agricultural extension services. But the role of Vigyan Mandir was seen in a different light. Thus the analysis of soil or water was not seen as the end utility, but as a means to educate the rural population to the ways of science. This was indeed a unique and interesting concept. Given the limitations of the Vigyan Mandir Officer, she/he may not be in a position to give solutions to all the problems identified through soil analyses, but she/he could show by simple experiments how certain soils lack certain essential ingredients. Similarly she/he could show how diseases spread through parasites. This was seen as the essence of relevant scientific dissemination.

The library wing was to have a well stocked library and a reading room. The library was expected to make available scientific and technical knowledge of higher order. The library was to be equipped with popular

6 Jitendra Nath Basu , Indian museum movement, Calcutta : Benson's, 1965,p.33.

7 Abdur Rahman, Triveni: Science, Democracy and Socialism, Indian Institute of Advanced Study 1977. P.88.

8 Abdur Rahman ,Trimurti: science, technology & society: a collection of essays P eople's Pub. House, 1972, p.87.

9 See chapter VI of the assessment committee report on Vigyan mandir, New Delhi, Vol 1, 1960

scientific literature in regional languages. With this in mind, the Ministry of Scientific Research and Cultural Affairs drew up a scheme to encourage production of popular literature in regional languages. The Vigyan Mandirs were to disseminate scientific information through magic lanterns, 16 MM projectors, easy tracts, books, charts, maps, talks, meetings, conferences and exchange of views. As a part of the activities of this wing, the VMOs were expected to organize regular lectures and demonstrations.

Vigyan Mandirs were to have a museum that would be stocked with samples of geological specimens and flora and fauna of the local area. The science museum was to serve dual purpose. The specimens were to be collected and displayed with suitable explanatory notes in regional language for the benefit of the rural population. Such a collection was to make the people in the locality aware of the potentialities of various objects of interest from the scientific or other points of view for those particular localities. Moreover the VMOs were expected to undertake field studies to collect them. They were to enthuse the local population into such explorations. The young men of the locality were to explore, make the collection and bring them to the Vigyan Mandir. With the help of national laboratories the specimens were to be identified properly and then exhibited. Thus, by the very act of building a local museum, it was sought to inculcate a spirit of inquiry in the young men and offer a sense of participation along with some preliminary training in the scientific methods of collection.

Rural science centre or science clubs were to attract progressive school teachers and involve children and it was environed that through them gradually scientific knowledge and scientific attitude would also percolate among the older generation.

In the minds of the protagonists, the Vigyan Mandirs were to not only advise people but were to also learn from the people. Vigyan Mandir was to study the local practices and habits and where necessary, refer them to higher institutions for proper appraisal. They were expected to garner village wisdom, born out of practical experience before it was irrecoverably lost. The Vigyan Mandir was to be built from below, letting the needs of the people and their demands to strengthen the structure from below. Vigyan Mandirs were to act in symphony with other developmental activities in the block such as Community Development Scheme, National Service Scheme and so on. Vigyan Mandirs were to act as catalytic agents to supplement and not to supplant the work of other agencies.

Expansion in Snail Pace

The initial effort began in the first five year plan and after the establishment of the first Vigyan Mandir near Delhi, two more followed at Masauli in Uttar Pradesh and T.Kallupatti in Madras State (present Tamil nadu) in the same year. When the Ministry of Scientific Research and Cultural Affairs came into being in April 1958, there were 18 Vigyan Mandirs distributed in 15 states and union territories of India. The proposal was that, by the end of the plan period, 320 of them; one for each district would be established. At the end of 1958-59, 31 Vigyan Mandirs were in position. By 1960, the total raised to 38 in 17 states and union territories. By 1963 the total went up – marginally- to forty nine. Mostly the Vigyan Mandirs located in blocks were covered under the Community Development Project.

The Government announced that it will establish *"125 Vigyan Mandirs throughout the country during the Second Five-Year Plan period."*[10] This was reduced to 92 Vigyan Mandirs with a budget of 50 lakhs. However the reality was that, only 49 could be set up. During the second year plan, the Vigyan Mandir was under the Ministry of Scientific Research and Cultural Affairs, but under the rules of allocation of work of 1962, the control of Vigyan Mandirs was transferred to Education Department in the central government. Following this, the Education Department mooted that during the third five year plan it would institute at least one Vigyan Mandir in each district making the total to 320. However, the scheme was transferred to state governments, with central government providing only three fourth of the expenses. The response from the state governments was lukewarm. While governments of some states like West Bengal, Orissa, Madras, Madhya Bharat, Travancore-Cochin, Saurashtra and Bihar welcomed the establishment of Vigyan Mandirs in their States'[11], the government of Madhya Pradesh officially intimated that they had no plans for increasing the number of Vigyan Mandirs during the fourth plan period.

10 The Hindu, Plan for Vigyan Mandirs, dated April 15, 1956

11 Plan for Vigyan Mandirs,The Hindu, dated April 15, 1956

Enthusiastic Response

One of the expectations from the Vigyan Mandirs was that, the officials would conduct field work and collect geological specimens, flora and fauna of the local area and such other scientific activities. Number of Vigyan Mandir officers did take efforts in this direction. The geological survey and its subordinate offices distributed what they had taken into duplicate collection, to schools and Vigyan Mandirs[12]. A box containing forty mineral specimens were made by the GSI and distributed to various Vigyan Mandirs. Short courses of lectures were offered to Vigyan Mandir officers on methods of identifying minerals[13]. These efforts appear to have been partly fruitful, and as a result of this scheme, numerous specimens were received at the Petrology division in Calcutta for identification. They were analyzed and reports were sent back to the concerned individuals[14]. Botanical Survey of India was marshalled into developing and supplying mounted sheets of medicinal and other plants. Agricultural department made colour plates of Indian insects and pests –both useful and harmful for supplying to Vigyan Mandirs. Zoological survey of India got rare specimens from the Vigyan Mandir officers who did field work and collected samples. Ravi Prakash, a Vigyan Mandir official from Bhopal studied the atrioventricular bundle in the heart of the banded krait, *Bungarus fasciatus* and reported his findings in the PNIS of India[15].

Vigyan Mandir's mandate evoked enthusiastic response. G.K.D Roy, an officer of the Vigyan Mandir of Assam and Arunachal Pradesh collected a rare fossil from Barail reserve in Cachar hills and sent it to Birbal Sahani Paleobotany Institute[16].A teacher in Madurai participated in a Vigyan Mandir science competition and won the first prize by contributing a model[17]. A team of young trainee nurses were enthralled at the films on development and health exhibited at the Nilokheri Vigyan Mandir and enamoured by the demonstration of hygienic food preparation, testing of adulteration to women in rural areas[18]. Gulabratna Bajpai's[19] popular science book was published in Bengali by Vigyan Mandir. Reports made in the Parliament indicate that the Vigyan Mandir organised lectures, soil and water testing, films shows and so on. Shri B.K Sharma[20], Vigyan Mandir Officer from Surendra Nagar put the popular beliefs to scientific test. Does onion, ginger or garlic deter snakes as the popular assumptions go? He observed the response of three snakes in the cage to onion, garlic and ginger and found that they did not have any effect on them, but naphthalene balls made the snakes sluggish and after 24 hrs they died one by one within three days.

Assessment Committee Report and After

After the second five year plan, the Ministry of Scientific Research and Cultural Affairs instituted an Assessment Committee on Vigyan Mandirs[21] to review their working and consider the desirability of enlarging their scope by addition of cultural activities. The committee was chaired by the legendary parliamentarian Balwant Rai G Mehta and had illuminaries like Bhargav, Muhammed Khuda Bukhsh, Shrimati Yashoda Reddy, C. Ramachandran, Thakur Phool Singhji as it's members and Shri N.K Sreenivasan as its secretary. The committee examined as to, how far s to, how far the Vigyan Mandirs were successful in accomplishing the objectives for which they were set up, the difficulties they faced and how these difficulties could be overcome.

Further, Vigyan Mandirs were being instituted by CSIR, under the Ministry of Scientific Research and Cultural Affairs. The role of the state government had in the institution and operation of the Vigyan Mandir was another question that loomed large and the committee examined the changes that were required in the nature and extent of assistance given by the state governments. The committee also examined the need of supplementing the

12 Indian Minerals, Vol 16, 1962, p.35

13 Ibid p.104

14 Ibid p.109

15 Ravi Prakash, Proceedings of the National Inst of Science of India, Vol 22, Part 2, (Biological Science) 1956, pp255-258.

16 The Palaeobotanist, Vol 9-11, 1962 pp37

17 Teacher Educator, Vol 5-8, 1961 p.9.

18 Nursing Journal of India, 1961, p.184

19 Akarshan Shakthi (On magnetism), Gulabratna Bajpeyi, Publihsed by Vigyan Mandir Culcutta 1954

20 "science notes and news, Current Science, Vol 27, 1958, pp512

21 Order M-SR&CA, No 1/19/59-VM-1 dated Sep 14, 1959

Vigyan Mandir's with an additional cultural wing, along with the library, laboratory and museum wing. The committee visited 19 out of the total 38 Vigyan Mandirs; in particular the committee focused on those Vigyan Mandirs that had been working for at least three to four years. The committee also sent a questionnaire, containing 27 questions eliciting response from the Vigyan Mandirs. Further it also visited all the states and met the representatives of several educational and social institutions, and hundreds of people to garner their views. Subsequently it submitted a detailed report in two volumes[22]. After giving a general picture of the country where scientific spirit was not very strong, the Report said "*It is into such a picture that the Vigyan Mandir Scheme has brought a ray of light and hope."*[23] Further the committee report noted that ".. *we must here and now take recourse to every method and channel of communication to spread scientific knowledge among the people, or we shall be compelled to fall behind. It is against the background of this grim situation that, we should study the implications of the Scientific Policy Resolution of the Government. We are afraid that, as in many other things, while enunciation of policy is emphatic and clear, its implementation is left vague and uncertain."*[24]

Yet, the committee after examining the working of Vigyan Mandirs and taking into view all the opinions received, candidly concluded that "*the work of these Vigyan Mandirs so far has not been satisfactory or up to expectations"*[25]. When the ground situation was examined in micro detail, the committee found many different lacunae. The committee found the Vigyan Mandirs to be 'little islands of science' in the Indian landscape and if these nascent institutions were to perform the role of spreading scientific temper then they needed to work properly.

For example, the two Vigyan Mandir Officers were supposed to have complimentary qualifications. If one was a qualified in agricultural sciences, then the other had to be drawn not from the same science discipline, but from another branch. So that, these two together would be able to meet the scientific needs of the Vigyan Mandir. However, practical operation many times resulted in both the officials posted in a Vigyan Mandir being drawn from the same discipline. The need for a rational basis for posting of staff for proper balancing of work was apparent.

In a scathing attack on the callous manner in which the establishment was treating the subject, the committee observed "*The Vigyan Mandirs suffer so much from centralised control that they can be described as 'all brakes and no engine'. While the success of the experiment must depend on the initiative and personality of the officers, the machinery is not geared to produce the best results. The Vigyan Mandirs were brought into existence to meet a great need of the country but nothing worthwhile appears to have been done to create the conditions conducive to their healthy growth and development. All that has been done is to plant a few Vigyan Mandirs here and there. Sufficient thought does not seem to have been given to the need to integrate them with bigger institutions engaged in educational or rural reconstruction work. It is not, therefore, surprising that many Vigyan Mandirs have not succeeded in creating a favourable atmosphere."*

Despite the platitudes paid to the Vigyan Mandir and the VMOs, the committee noted the shoddy treatment that they were being subjected to by the administrative machinery of the government. The committee observes *"... even though the VMOs were to play a crucial role in the community development, they had very little actual power and freedom to work. They were given a paltry sum of Rs 20 as an impressed amount to meet the continent expenses, but even to spend that they would have to wait for the sanction from the central government...."* The then Minster for Scientific Research and Cultural Affairs, Humayun Kabir admitted[26] that "*When they wrote letters to the central government, for months together there was no reply"*. The VMOs were handicapped by the bureaucratic hurdles and apathy of officialdom.

The committee went into what needed to be done to mitigate the situation. It recommended a set of duty chart to the VMOs. The committee observed, *"The duties and functions of the Vigyan Mandir Officers have not been clearly defined. A schedule of duties is not available and when questioned, Vigyan Mandir Officers informed us that no instructions had been issued about the exact scope and nature of their work. The Vigyan Mandir Officers are expected to enlighten the villagers on the programme and enlist his interests and secure his participation. How efficiently they do that depends on their own appreciation of the programmes. In the absence of a clear-cut*

22 Assessment committee on Vigyan Mandirs 1959- Ministry of Scientific Research and Cultural Affairs (Vol 1 and 2)- Publication no 59, New Delhi 1960.

23 Ibid

24 Ibid p 64

25 Proceedings of the Rajya Sabha, 20 Apr 1961pp216-262.

26 Rajya Sabha motions, 20 Apr 1961, pp 215-262

scheme, many Vigyan Mandirs have not succeeded in making an impact on the rural population. No clear-cut programme of work has been given to Vigyan Mandirs which carry on their activities in a rather perfunctory manner. This deficiency has to be remedied by giving proper shape and content to the programme, bearing in view the objectives of the scheme and the capacity and limitations of the Vigyan Mandirs." From family planning to soil testing; from organising science clubs to providing support to community youth clubs; number of tasks were set out by the committee.

It advised that the VMOs should be given training on being sensitive to the psychology of the village adults and they were expected to host regular lectures and demonstrations keeping that in mind. Through these lectures and demonstrations, the villagers were to be educated about the causes of common diseases, first aid, balanced diet, nutrition etc. Elementary ideas of genetics, moral and sexual hygiene and child care were also on the agenda. Indeed, one of the crucial roles of the VMOs was to educate the need of family planning amongst the rural people.

The committee noted that, minimum staff strength would be required to ensure proper functioning of the Vigyan Mandirs. It suggested that both the Vigyan Mandir officer and Assistant Vigyan Mandir Officer were to at least have a good master's degree in Science. Preferably, the senior officer in a Vigyan Mandir should be an M.Sc in agriculture with research or teaching experience while the junior officer may be drawn from the physical sciences, preferably chemistry. While all else being equal persons with some field experience and ability for writing and lecturing on popular scientific topics in the regional languages were to be preferred. The committee was of the view that, one of the two officials should be woman. The Vigyan Mandir was to have a laboratory assistant, a mechanic who was also to act as a driver. The scientific and technical staffs were to be assisted by a clerical assistant. The Vigyan Mandir was to be provided with a mobile van fitted with generator and fixtures for transporting laboratory equipment and audio-visual aids to interior rural areas.

The committee also suggested that the Vigyan Mandirs should be transferred to State Government, and the responsibility of administering Vigyan Mandirs may be, according to an agreed pattern of programme and financial assistance from the Centre. The general view expressed was that, Vigyan Mandirs may be under the State Education Department.

Dr Niharranjan Ray[27] noted that, the recommendations that the assessment committee had made as to *"the programme of work of the Vigyan Mandirs was much too long and too good to be realistic".* He noted that the "*poorly paid VMOs were expected to do as many as 35 and if the extension services were included then 38 items of work"* and observed that "*this is all moonshine*

Natural Death of Vigyan Mandir

Within two decades of the establishment of the first Vigyan Mandir, popular science commentator noted "*The Vigyan Mandirs .. died a natural death*"[28]'. H.S Bhola, adult education expert observes that the "idea was to establish many Vigyan Mandirs in rural areas, where farmers could come to look at specimens and exhibits, to use instructional materials, view films and even conduct simple experiments". While the project was introduced with great enthusiasm some 20 years ago, Bhola rues that "*There is no mention of the scheme in recent reports of the government of India. There is no other remnant to be seen, ... of Nehru's dream of universal scientific literacy for India."* [29] and Niharranjan Ray[30] lamented that, "*Nehru's experiment of establishing Vigyan Mandirs in villages, …. failed, due to the bureaucracy as well as the reluctance of scientific workers to engage with the villagers."*

Buried inside the report is perhaps one of the crucial factors that made Vigyan Mandir experiment a failure. No systematic attempt was made to associate the 'people' with the working of Vigyan Mandirs. In the absence of any active effort to mobilize local support, it is not surprising that many Vigyan Mandirs did not evoke any popular enthusiasm. The work of Vigyan Mandir was seen as a passive one; a center that disseminated scientific information; not in the active tone of the need to mobilize marginalized sections to change the stifling outmoded social customs. Slowly and steadily, Vigyan Mandirs were not even seen as a reformist, leave alone as the revolutionary agency of the 'missionary state' to make massive social change; but was seen as an institution that

27 Rajya Sabha motions, 20 Apr 1961, pp 215-262

28 Amalendu Bose, Mobile Science Exhibition, Unesco, Radiant press, Culcutta, 1983, p.9.

29 Bhola, H.S., "Scientific Literacy for Adult Learners," Bulletin of the Unesco Regional Office for Education in Asia, Number 18, June 1977, pp. 235-242.

30 Arabinda Poddāra (ed) Man, science and society: proceedings of a seminar, Indian Institute of Advanced Study – 1970, p. 385.

would aid in disseminating the priorities set by the central government such as 'green revolution' .The Vigyan Mandirs thus did not die a 'natural' death; but were stunted and limited and ultimately made irrelevant by taking away their sole mission: that of concertizing under privileged section.

Another factor that led to the disorientation appears to be the confusion regarding the goals and aims of Vigyan Mandir. There was always a tension between the 'extension' and 'dissemination' goals between 'knowledge production' and 'reproduction' goals of Vigyan Mandir. Time and again, questions were raised about the 'utility' of Vigyan Mandirs. The number of soil and water samples that were tested, the qualifications of the medical professionals aiding in treatment etc were questions that emerged again and again. Humayun Kabir Minster for Scientific Research and Cultural Affairs was at pains to clarify that the Vigyan Mandirs were not extension services. Humayun Kabir underscored that the Vigyan Mandirs were "*not so much service institutions, but were institutions that were meant to bring about a scientific atmosphere in our villages. They were essentially centres for the dissemination of knowledge and only secondarily service institutions".* Observing that the "*Vigyan Mandirs were conceived primarily as centres for disseminating scientific knowledge and creating a scientific atmosphere in the villages"* , he stated that, "*there was a misunderstanding in considering them to be service agencies engaged in soil analysis or analysis of health problems or applying actual remedial measures*"

Shri Ram K Vepa, a reputed social critic noted with alarm that, the Vigyan Mandirs were being abolished as early as 1968, even before the end of the Fourth Plan Period. He contended that the "*failure is largely administrative in character rather than due to any basic defect in the concept itself*". First operated by the Central Government itself, they were later transferred during the Third Plan Period to the State Governments, which was indeed the right approach. At the State level, however, they were tossed between several ministries, such as Planning, Education and Agriculture, each of which did not quite know what to make out of them. The decision to abolish them altogether seems to have been considered the easiest way out, but must be regarded frankly as "*a confession of defeat in utilizing an institutional framework which was set up with the best of intentions".*

The criticism of the Vigyan Mandirs also emerged from the civil society. The Link[31], a radical periodical reviewed the progress of the Vigyan Mandirs and opined that 49 Vigyan Mandirs that were established around the county to popularize science was woefully inadequate to the size of the country and magnitude of the problem. Vidura, a journal of the Press Institute of India evaluated that the Vigyan Mandirs, that were designed to serve the rural areas were in a 'neglected state'. C.Subramaniam, noted administrator observed that the Vigyan Mandirs were thinly manned, indicating inadequate staff support for the initiative.

The Vigyan Mandirs had audiovisual displays, exhibits, training facilities and utility services such as soil testing, etc. and a group of motivated young people to run them. Within a decade, the entire chain was in shambles. Audio-visual material, once prepared, was never updated; projectors had no spares; training programmes stopped for lack of instructors; soil could not be tested for want of chemicals and new concepts became fewer and fewer[32].

Amongst the influential sections of the society in the 1980s Vigyan Mandir lost its sheen and the idea of building massive science museums (science centers) became the dream. Writing in UNESCO's journal, Museum[33], Saroj Ghose observes that "*Vigyan Mandirs had to function in isolation without any back-up for the creation of new exhibitions and hence failed utterly*". As a replacement for the failed Vigyan Mandir scheme, the author advocates "developing a science museum movement in the country" and shows the impressive Nehru Science Center at Mumbai as the exemplar.

A prestigious journal of administration[34] observed that "*Vigyan Mandirs were at one time conceived to provide information to the agriculturists and generally act as a forum for purposeful discussion on current topics*" and noted that "*they have since been closed down*". Contending that in any case, the Vigyan Mandirs were very few as well as ill-organized, it concluded that the consequent impact on the public was almost nil.

At a much later stage, a task force set up by the Planning Commission identified the primary cause of failure, as lack of guidance, co-ordination and infrastructural support. The Vigyan Mandirs had to function in isolation without any back-up for the creation of new exhibitions, organisation of new activities, continuous updating of

31 Link, Vol 5, Iss 26-53

32 Saroj Ghose, Science Museum beyond four walls, Intl Journal of Museums, No 150, Vol XXXVIII, 1986, pp100-106

33 Ghose, S. (1986), Science museums beyond their four walls. Museum International, 38: 100–106.

34 The Indian journal of public administration: IIPA, Delhi, Volume 15, Issue 2, P.607

information and extension of training facilities. In effect, scrapping the idea of Vigyan Mandirs, the committee suggested a centrally coordinated science museum movement in the country. This is another story.

While in the states, many of them either closed down these centers, or reorganised them into full fledged service/ extension centers. Soon, the objectives of the centers became skewed and dissemination of agriculture related information became the only priority under the compulsions of the green revolution. Today, none of the 'Vigyan Mandirs' exist; though a network of Krishi Vigyan Kendras (Agricultural Extension Centers) dot the rural countryside.

The experience of Vigyan Mandir experiment shows, how, just within few decades in the post independent India, 'scientific temper' in practice became paternalist reform, closely aligned with the new dynamic of planned modernisation and the nationalist enterprises. The empowering and conscientising goals were hardly taken seriously by the state.

Strand 2

Cognitive and Affective Studies of STME

Students' Understanding of Classical Ideas in Quantum Mechanics

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Quantum mechanics (QM) is one of the core subject areas in undergraduate physics curriculum and many of the advanced level physics courses involve direct or indirect application of the concepts and ideas taught in quantum mechanics. On the other hand, proper understanding of quantum mechanical interpretations require an optimum level of understanding of fundamental concepts in classical physics such as energy, momentum, force and their role in determining motion of the particle. This study is an attempt to explore a group of undergraduate students' mental models regarding basic fundamental classical concepts which are actually the stepping stone for appropriately understanding and visualizing QM. The data and analysis presented here elucidate the challenges students face to understand the classical ideas and how that affects their understanding of QM.

Introduction

The appreciation and application of fundamental concepts in quantum mechanics (QM) play a pivotal role in the development of various branches of modern physical sciences such as condensed-matter physics, high-energy and nuclear physics, statistical physics, optical physics and many more. In addition, the upcoming field of quantum information science which aims to revolutionize the technique of secured information exchange requires an in-depth understanding of basic concepts in QM. Introduction of fundamental concepts and formulations of QM begins at the undergraduate curricula and usually, an effort is made to deliver the concepts through citing examples from experiments which helps in students' comprehension of the involved concepts. However, there remain many concepts associated with wavefunction, momentum-space, wave-packets, expectation value etc. for which practical examples having a direct correspondence with experiments, that are comprehendible at undergraduate level, are rarely available for facilitating pedagogy. It is also assumed that the students attain a suitable level of mathematical ability for appreciating the formulations alongside their first course on QM or they are already acquainted with them before the course begins. However, it is apparent from various investigations and researches in the area of physics education research (PER) that students face difficulty in understanding various aspects of basic QM such as probabilistic interpretation of particle location [1] and concepts related to probability density [2], measurement in QM and time-development of quantum states [3] and many more [4-6].

A vast variety of issues associated with learning of QM can be attributed to the preconceptions existing in students' mind before they make their first rendezvous with quantum mechanical interpretations. These preconcepts may be the result of their personal experiences or a consequence of classroom teaching of other subjects. A few researches have shown that the physical interpretations of mathematical results in QM are strongly affected by the students' understanding in other areas of physics such as classical mechanics or electromagnetism [7, 8]. In many situations, students may oversimplify the problems viewing from classical framework which could lead to alternate conceptual framework. It becomes all the more challenging for those students who face conceptual difficulties in understanding classical physics. For example, there are students who find it difficult to relate the concepts of force, energy and momentum to determine the motion of the particle and understand the dynamics of the system. On the other hand, many of them experience difficulty in relating concept of probability of finding particle with simple physical quantities such as force and energy. As a result of this, their difficulties are enhanced by manifold times, as far as visualizing QM concepts are concerned. In addition, the abstract framework and mathematical sophistication associated with QM teaching adds to further difficulty in visualization and concept building.

Objective and Method

In order to appreciate the problems faced by students at the preliminary level for understanding QM, we choose to focus on the students' understanding of relationship between fundamental physical quantities such as force, energy, momentum and their role in determining the motion of a particle. Since, quantum mechanical phenomenon is beyond the realm of day-to-day observation, the visualization of concepts or visual interpretation of QM formulation by the students provide a direct reflection of the mental models that they have developed. In order to ascertain the students' visualization aspect, we chose a tool known as Quantum Mechanics Visualization Instrument[1] (QMVI) [9, 10]. QMVI is designed to test conceptual and visualization understanding in QM. To focus on conceptual understanding, the authors have tried to construct questions which require little or no mathematics. However, the students need to appreciate the relationships between various physical quantities and their role in determining dynamics (both classically and quantum mechanically) of the system [9]. The tool is in the form of multiple choice questions with five options out of which only one is correct. For our purpose, we chose question nos. 2, 3, 4 (Q2, Q3, Q4 are given in appendix A) from QMVI and administered the questions to 10 students (S1-S10) of a government-aided institute engaged in teaching-learning and research of basic sciences, namely National Institute of Science Education and Research (NISER) at Bhubaneswar, India. At the time of administering the questions, the students had already credited one course on classical mechanics (includes Lagrangian and Hamiltonian formulation), one basic course in QM (includes solution of Schrodinger equation for various potentials, time-independent perturbation theory etc.), two courses on electromagnetism (includes static electricity & magnetism, boundary value problems, Maxwell's equations, dipole radiation, special theory of relativity etc.), level-1 course on statistical mechanics (includes basic thermodynamics as well as statistics of classical and quantum systems) and one basic course on condensed-matter physics. Based on the written responses to Q2, Q3 and Q4, all the 10 students were interviewed in detail where the emphasis was to unravel their mental models. The interview was essentially meant to unleash the method of reasoning adopted by the students so as to obtain a clear picture of the difficult zones in their comprehension of QM.

Data Summary

The students' response to Q2, Q3 and Q4 of QMVI is summarized in Table-1 below. Q2 (refer *Appendix A*) of QMVI primarily probed the understanding of "time-spent" by a particle with a constant energy, in "different regions" of potential well visualized from a classical viewpoint [9]. The students were expected to understand that the time spent by a particle in a region exhibits an inverse dependence on 'speed' or 'velocity' and the 'velocity' is less in regions where potential energy is greater.

	opt. (a)	opt. (b)	opt. (c)	opt. (d)	opt. (e)
Q2	S7: (a) Time spent PE(V), or time spent 1/KE, assuming E = PE+KE (commits an error in taking sign which lead to incorrect ordering of terms given in the option)	S10: (a) Particle will stay in the region where (binding) force, F =V/*x*) is maximum (b) For region III, it is not possible to calculate slope	S3: (a) Time spent PE (V) Time spent 1/KE as E = PE+KE = constant (Commits an error in ordering the terms given in the options) S4: Comparison to ground state wavefunction of harmonic oscillator potential. S5: (a) Time spent force (= V/*x*) (b) discontinuity in region III implies force is maximum time spent is maximum (c) Force in region II and IV same, as PE (V) remains constant S6, S9: (a) Time spent force (= V/*x*) (b) resemblance and comparison with U-shaped potential in classical mechanics (c) maximum time at the bottom of potential well	S1, S2: (a) Time spent PE (V) (b) Time spent (1/KE), as E=KE+PE S8: (a) Time spent 1/velocity (or KE) 1/depth of well at that point (b) Depth(III) > Depth(II) > Depth(IV) > Depth(I) t(III) < t(II) < t(IV) < t(I)	
Q3	S6: P 1/PE (V), irrespective of its sign	S1,S3: (a) P 1/KE (b) 'P' will be zero at point 'a' because particle will never cross that region S2: Guessed an option without any		S10: (a) P 1/PE and P T (b) 'P' can never be infinity Fig. (I) is incorrect representation	S4: (a) P Time spent 1/KE (b) KE not equal to infinity at point 'a' P 0 S7: Comparison to simple

1 A copy of QMVI may be obtained from http://robinett.phys.psu.edu/qm. For details, Prof. R. W. Robinett at rick@phys.psu.edu may be contacted.

		logic S5: (a) P(x+dx) 1/PE (b) P(x) = dP(x+dx)/dx as given in Q3 derivative of Fig. (I) that is Fig. (II)			harmonic motion 'P' is maximum at extreme points S8: P PE or potential (V) S9: (a) 'P' is maximum where F = V/x is maximum (b) unsure about infinite boundary at x = 0
Q4		S1: DOD no. of times mass crosses a given point during oscillation (for motion A)	S2: DOD 1/velocity (overlooked the motion B) S10: (a) DOD 1/velocity (b) Invokes uncertainty principle by observing dots to represent position of particle	S3,S4,S5,S6,S7,S8,S9: DOD 1/velocity	

Table 1. Summary of students' responses to Q2, Q3 and Q4 of QMVI (F: Force; KE: Kinetic energy; PE: Potential Energy; P: Probability; DOD: Density of Dots); (a), (b)... show multiple points made by same student

The written responses of the students distinctly indicated that the routes adopted to reach an answer varied widely. In the interview, a few students (S5, S6, S9) choosing option (c) argued that the time spent by a particle would be more in those regions where the force experienced by it, would be more. When probed further, two of them (S6, S9) suggested that they assumed the 'force' to be 'attractive' in nature essentially due to their experiences in problems in classical mechanics where they find similar but continuous potential energy variation. In the 'U-shaped' potential energy well encountered in classical mechanics, the particle is in equilibrium at the bottom of potential well and hence, it spends maximum amount of time in that region. Also, the students choosing option (c) were influenced by the mathematical relation $F = -\partial V/\partial x$ which relates potential energy with force. According to this relation, force would be same in those regions where the slope is identical and hence, time spent in regions II and IV would be same. Interestingly, S4 drew resemblance of the potential energy variation to harmonic oscillator problem and connected the time spent to the quantum mechanical probability for ground state wavefunction. Hence, the time spent close to the centre of the well is longest and due to symmetry S4 assumed that in regions II and IV, the probability would be identical. Only one student (S7) chose option (a) with the argument that time spent in a region is directly proportional to the magnitude of potential energy in that region. He added that the force experienced by the particle is irrelevant for determining the answer in the present context. However, he acknowledges that he committed a mistake in ordering the time't' and hence, marked an incorrect option.

An interesting point was revealed from interviews with regard to the way in which students approached the problem. A vast majority of them resorted to some practical and well-known examples such as an 'oscillating bob' or motion of a 'mass connected to spring' in order to identify the relationship between fundamental physical quantities such as energy, force, velocity and acceleration. It was also observed that by scaffolding in terms of helping students recall the definitions of concepts such as energy, force, acceleration, two students (S3 & S5) who chose option (c) before, could identify the problems in their logics and hence changed their answers in the interview. An important observation was that many students inevitably attributed 'force' as a source of 'binding' or 'restricting' the particle's motion. Further investigations through informal discussions with teachers and revisiting the standard textbooks in classical mechanics revealed that the detailed and thorough discussions on potential and particle's motion due to an 'attractive force' was lacking. It could be suggested that by focussing on similar problems, teachers can help students to experience a smoother transition to QM from classical mechanics.

Q3 of QMVI essentially required that the students identify a classical probability distribution for particle (with a definite energy) in a potential distribution (attractive in nature) that had an infinite potential at one boundary. The recipe to reach the correct answer is similar to that in previous question (Q2) with a small but significant addition of infinite potential at one boundary (x = 0). Hence, we anticipated a pattern of answers and reasons resembling the previous question. However, it was not the case. It is worth noting that two options ((b) and (e)) represented a situation in which the probability of finding the particle was small in regions where the potential energy is less.

The student (S6) who chose option (a) gave an identical argument that he gave in the previous problem i.e. in problems encountered in classical mechanics, the particle spends maximum time at the bottom of a U-shaped well where potential is minimum. During the interview, S6 accepted that he is confused between options (a) and (d) but intuitively he thinks option (a) would be the correct response. S10 gave a similar logic as that given by S6 but was averse to the idea that probability could tend to infinity. Therefore, he found option (d) to be more appropriate. Amongst the students who chose option (b), S1 and S3 adopted the expected (and correct) route of identifying the inverse relation between probability and velocity of a particle which in turn, depends on the difference between total energy and potential energy of the particle. However, they explained that the particle would never 'cross' the $x = 0$ boundary and therefore, the probability of finding the particle at $x = 0$ would be zero. For this problem, S2 did not have any idea about relating mechanical energy to 'probability' of finding a particle and acknowledged that he guessed a choice.

The students choosing correct option (e) expressed an expected logic except S9 who argued that the probability of finding a particle in a certain region is directly proportional to the magnitude of force (=V/*x)* experienced by the particle. The variation of potential in this question suggests that the magnitude of force and hence, probability is small when the potential curve is flatter, and large when the curve turns steeper. However, S9 pointed out that the infinite potential boundary created substantial confusion because the derivative of potential with respect to space at that point would tend to blow up leading to physically unacceptable situation. Being unable to circumvent the state of confusion, he went ahead with option (e) but mentioned that he is not certain about his choice.

Q4 of QMVI needed the students to visually correlate a practical situation (an oscillating mass and an accelerating particle) to a pictorial representation in which large numbers of points depicting the position of the particle were captured randomly (refer *Appendix A*). The familiarity in terms of physical realization of the situation entails an overwhelming majority of the students opting for the correct choice (d). From the written responses as well as from the interview, we found that the students showed an increased level of understanding in terms of relating a visual data to a physical quantity in the classical sense. S1 provided an alternate thought by mentioning that an oscillating mass would 'pass' the centre of oscillation 'twice' in one period and therefore, the snapshots at equal intervals would exhibit more density of points at the centre of oscillation than that at the edges. However, on scaffolding, S1 and S2 could reason out the correct option. Interestingly, S10 did not take the standard route to figure out an answer and instead, expressed that the scattered points described in the question pertains to measurement of particle's position. Higher density of points (dots) signifies better accuracy of measurement of position. Also, according to uncertainty principle, the uncertainty for measurement of position is inversely related to that for velocity or momentum. Therefore, the higher density of points implies greater uncertainty in measurement of velocity and hence, the particle is accelerating in the direction where the particle exhibits greater density. An implicit assumption made by S10 was that the uncertainty in measurement of velocity directly depends on the magnitude of velocity or the speed.

Data Analysis and Discussion

Looking at the above observations from the perspective of learning, it came out very clearly that, students while trying to deal with new situations seems to borrow heavily from their previous understanding of the related concepts. This observation corroborates an important assumption of constructivism that previous knowledge of the individual plays a pivotal role in construction of new knowledge. In Q2, though learners were given a hypothetical discontinuous potential-well; they found it to be visually similar to the potential well of a known situation i.e. the potential energy variation of an oscillating bob. Also the physical variables discussed were the same namely potential energy, total energy and position. On that basis, it seems that they have assumed the results of the known situation can be carried to unknown situations as well. Perhaps due to visual similarity, this assumption was so strong that they overlooked the differences between the two situations and the implication of these differences on the motion of the particle. In this case few learners drew the visual similarity between the graph of potential energy of an oscillating bob and the graph in the question. Thus, they invoked the same relation and tried to solve the problem on similar lines, overlooking or ignoring the differences in contexts. These observations also pose a question on the conceptualization of relations amongst various physical quantities by learners. It may also be attributed to the way concepts are generally taught in the class. For instance when we teach concepts like energy- especially kinetic and potential, we cite typical examples such as the motion of an oscillating bob and/or mass connected to spring. Thus learners seem to have a strong tendency to visualize the concepts through those examples. These examples may actually become a part of the conceptual structure itself, and hence even in an unknown situation or novel context, learners invoke the example and even a small similarity of novel situation to the familiar examples reinforce their idea to apply the result of the examples to novel situation.

In Q3, the condition of infinite potential at one boundary, proved to be very challenging for learners. Though the relation sought for was similar to previous question, the infinite boundary wall made all the difference. It brought out learners' confusion about whether the probability of finding the particle at the infinite boundary would be zero or not. It was also observed that students found it difficult to deal with concepts such as an infinite potential wall which are dealt in classical as well as in quantum domain frequently.

A significant point which was quite evident from the data was that learners always tried to relate the conditions given in the questions to some concrete physical situations. Data of Q2 is illustrative of this argument. In Q3 also the boundary condition posed a difficult situation to imagine thus became a challenge for students. They were unable to relate it to any physical situation and thus got confused. The ease with which maximum number of learners explained the correct solution of Q4, was elucidatory of the fact that concrete situations, facilitate in conceptualization. Higher number of correct answers and explanations for Q4 than for Q2 or Q3 may also be illustrative of the fact that relating the concept of probability to more abstract concept of energy and force was challenging for students. Velocity and acceleration are less abstract as compared to energy and thus more easily visualizable. It could also be noted from this study that even though the students have taken level-1 courses in classical mechanics and QM, many of them had misconceptions about energy and actual motion of particles in classical domain. For a few of them, the concepts of force, energy, momentum, and their relationship for ascertaining the probability of finding a particle is also not clear.

Conclusion

In this research, we tried to explore students' mental models and challenges faced by them in relating basic concepts such as force, energy, velocity to motion of the particle. The data revealed that learners visualize these relations variously. It was also found that preconceptions seem to play a very significant role in the way students construct new knowledge or deal with novel situations. Our data also indicated to an extent that concrete, physically realizable situations and examples help learners to conceptualize easily. One of the suggestions that we would like to put across based on this study is that the teachers may choose to try to illustrate the concept through various examples, rather than only one or two. It would help learners to understand the concept from various dimensions.

In addition we would like to mention that it is important for teachers to bring the attention of students to both -the differences and similarities between quantum and classical domains and how various concepts are interpreted and used in both domains. This was a small preliminary study to investigate learners' mind, which revealed significant points but a larger study with more number of students and an in-depth study with more number of questions to elicit students' conceptions would be helpful in ascertaining the presented results and may help in drawing general conclusions.

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Appendix A

Q2) The plot (Fig.1) shows a function of **potential energy** versus position (*V*(*x*) versus *x*) for a one-dimensional system. A dashed horizontal line indicates the value of energy *E* for a particle moving in this potential well, corresponding to a bound state system. Small regions, each of width *dx*, are indicated at several locations in the well. Order the **time spent** in each small position bin (*dx*), *t*(*I*), *t*(*II*), t(*III*), *t*(*IV*), from **longest** to **shortest** as the particle moves back and forth in the well.

a) *t*(*III*) > *t*(*II*) > *t*(*IV*) > *t*(*I*)

b) *t*(*I*) > *t*(*IV*) = *t*(*II*) > *t*(*III*)

c) *t*(*III*) > *t*(*II*) = *t*(*IV*) > *t*(*I*)

d) *t*(*I*) > *t*(*IV*) > *t*(*II*) > *t*(*III*)

e) *t*(*I*) = *t*(*II*) = *t*(*III*) = *t*(*IV*)

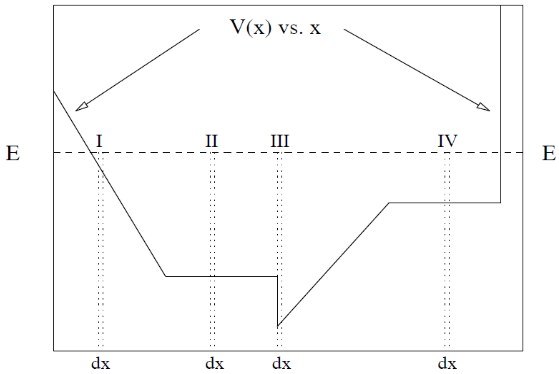

Fig. 1

Q3) A particle of energy *E* moves between classical turning points, a and b, in a one-dimensional potential as shown in Fig. 2(a). The turning point at a is defined by an impenetrable wall, while the one at point b is given by the intersection with *V*(*x*) curve shown. Which of the **classical probability distributions**, *P*(*x*), shown in Fig. 2(b) below, the potential diagram corresponds to this system? (Recall that the classical probability distribution is defined such that the probability of finding the particle in the small interval (*x*, *x*+*dx*) is given by *d*Prob(*x*, *x*+*dx*) = *P*(*x*)*dx*.)

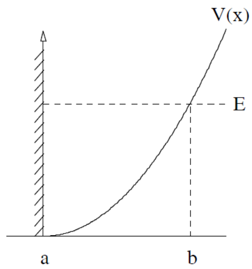

Fig. 2(a)

a) I

b) II

c) III

d) IV

e) V

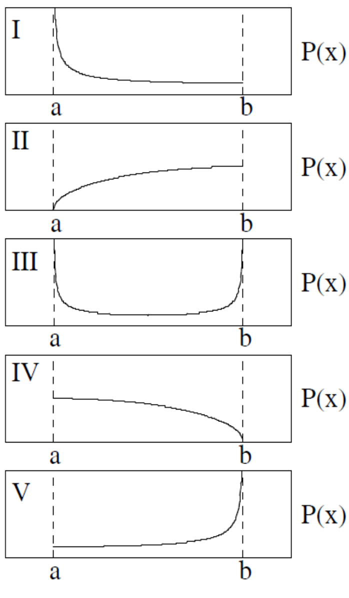

Fig. 2(b)

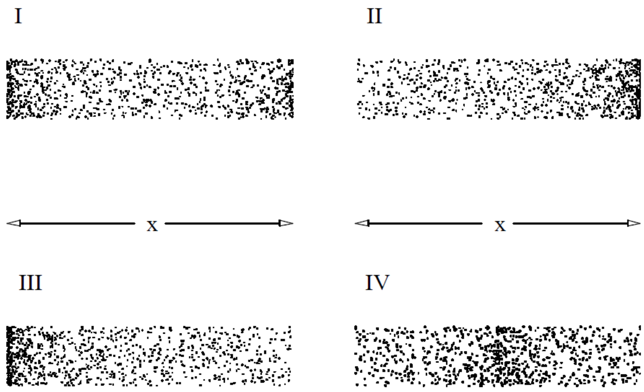

Fig. 3

Q4) The position of four objects with different types of motion in one-dimension are captured at a large number of random times in the computer-generated 'snapshots' as shown in Fig. 3. (The vertical spread in the dots is simply added to make the density of dots more clearly visible.) Two possible one-dimensional motions are:

A) A mass oscillating at the end of a spring

B) A mass undergoing uniform acceleration to the right, starting from rest

Which motion (A, B) goes with which 'snapshot' (I, II, III, IV)?

a) A: IV B: II

b) A: IV B: III

c) A: I B: II

d) A: I B: III

e) None of the above

Answer keys: Q2 – (d); Q3 – (e); Q4 – (d)

Teaching and Learning about Evolution and Natural Selection: Problems and Solutions

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We have analysed the difficulties in teaching and learning about evolution and natural selection. We have done this by reviewing textbooks and teaching methods, collecting data through questionnaires, and working with students and teachers individually, in classrooms, and in workshops in a few major cities of India. We conclude that students as well as teachers commonly have great difficulties understanding evolution and natural selection and using and integrating their understanding to analyse and evaluate problems in biology. We have found that the reasons for these difficulties are: (1) Evolution by natural selection is inherently difficult to understand because biology is complex; (2) Natural selection conflicts with our ways of thinking about the world, in particular with our tendency to think teleologically and our tendency towards idealistic or dualistic rather than materialistic ways of thinking; and (3) We may be lacking in sufficient scientific temper. We have developed teaching methods in order to assess and redress the problems we have identified.

Introduction

The problem of how to teach and learn about evolution in India is quite different from the situation elsewhere. In the west, particularly in USA, there has been substantial research to find the reasons why various people do not think evolution occurs. Researchers have found that the main causes are: (1) lack of understanding of evolution, natural selection, and the evidence for evolution, (2) lack of understanding of the nature of science, and (3) religious, political and social reasons (Allmon, 2011, Richards, 2008, Matthews, 2009, and references therein).

Although no one has conducted a survey or analysis of the general population in India, it is obvious, given the current state of education and literacy, that most people probably have never heard of evolution by natural selection. Since less than 5% of the population speak English and less than 10% of the population has access to the internet, this also limits contact with the subject (Satchidanandan, 2012, Wallraff, 2000). Perhaps the general population also does not have a good understanding of the nature of science.

We have found that even in elite institutions, students as well as teachers commonly have great difficulties understanding evolution and natural selection, and they also have difficulties using and integrating their understanding to analyse and evaluate problems in biology. We have found that this is related to their lack of understanding of the nature of science. In this report we will discuss these problems, the evidence, and analyse the reasons for the problems. We will then discuss the teaching methods that we are evolving in order to address these problems. Finally, we will discuss the possible reasons for the teleological thinking which makes it hard to understand evolution by natural selection.

Methods and Procedures

The methods we have used to study how biology teachers and students teach, learn, and think about evolution have been mainly qualitative case studies conducted in workshops and classrooms from 2007 to the present with students and teachers from a few dozen schools and colleges in Mumbai, Delhi, Pune, Hyderabad, Indore and areas near these cities. Most of the students and teachers with whom we have interacted have been based at elite English medium institutions.

Our analysis also relies on feedback and discussions at seminars, in email groups, and from published articles, for example from a large number of emails received in response to an article in The Hindu newspaper to commemorate the 200th birthday of Charles Darwin (Haydock, 2009). We do not claim that these results have a more general or quantitative significance.

What problems do students and teachers have in understanding evolution?

The students we have been working with have studied in schools in which evolution is included in the syllabus in Class X, and then in more depth in Class XII (except for students in the arts or commerce streams, who do not study evolution after Class X). In some cases evolution is mentioned as early as Class VII. Some of the students' problems in understanding evolution stem from the way they are taught, which is almost exclusively listening to lectures, reading textbooks, and memorising. These methods do not tend to motivate active involvement in learning. Another problem is due to the content that students are exposed to through teachers and textbooks (Haydock, 2012 unpublished). This often leads students to assume that evolution is teleological - i.e. that it occurs intentionally, for a purpose.

Problems in students' and teachers' understanding

We have used True/False tests to find out whether teachers and students hold some common misconceptions related to evolution and natural selection. When we administer these tests at the beginning of our evolution workshops, we find that biology students as well as teachers frequently think that evolution depends on the inheritance of acquired characteristics, that we have never observed evolution occurring because it is a very slow process, that organisms evolve with the purpose of becoming better suited to their environment, and that evolution is the survival of the fittest, meaning that animals with more muscles will survive and weaker ones will not survive.

This indicates serious problems regarding acquired characteristics, the timescale of evolution, and teleology. Although we have mainly studied teachers of Classes I to XII, based on informal conversations we suspect that even university lecturers may hold some of the same misconceptions.

On the other hand, we have not come across any biology student or teacher who says that they do not believe that evolution by natural selection occurs. Very rarely do they say that there is any conflict between a belief in evolution by natural selection and any religious beliefs that they hold.

We were surprised to find that confusions persist even about artificial selection. For example, one week after completing a session on artificial and natural selection (using plants in the mustard family as examples), we asked a group of BSc Biology students to write answers to the following: "(a) Explain in your own words how some kind of plant in the mustard family might have evolved through artificial selection; and (b) What is evolution by artificial selection?" Based on their oral responses it had seemed that the class had a fairly good understanding of artificial selection, but many of their individual written responses were unclear and insufficiently detailed. Here are some responses which indicate misconceptions and confusions:

> Student 1: (a) The kinds of plant species liked by humans in a locality would have been consumed by them more than other kinds (with undesirable traits). These uneaten other kinds, were the only ones majorly left to produce seeds and form the next generation. Over a period of time, these other kinds with specific traits represented the whole population of mustard. The mustard plant could then be said to be evolved in the direction of that trait. (b) Evolution where selection is done by humans.

This student has recalled some aspects of artificial selection, but has made a logical error in telling how farmers could produce a population with undesired rather than desired characteristics.

Following is how a Class VII student answered the same questions after a similar session on artificial and natural selection.

> Student 2: (a) The ancient man grew the wild mustard and saw some undeveloped, highly packed flowers and tasted it, they found that it was very tasty then they took some seed from that plant and cultivated the undeveloped tightly packed flower and by generation to generation they done the same thing intentionally to see what they will get and got a cauliflower; (b) Artificial selection is done by a human beign for some intention.

Student 2 seemed to have a fairly good understanding, except it is not clear whether she realised that a population of cauliflowers is produced, not just one cauliflower plant. Interestingly, the intentionality is rather tentative. Note that the farmers were never referred to as 'men' in the session, but gender bias appeared in the answer. This led to a discussion of statistics which show that most farmers in India are women, not men.

Some students realised that variation is necessary, and that variation can be due to environmental factors, but failed to understand that unless there is a heritable aspect to the selected traits there can be no evolution. This interdependence between genetic and environmental factors makes it inherently difficult to understand the mechanisms of evolution. It involves a dialectical logic to which most of us are not accustomed. Following are examples of this from a Class VII student and two BSc students:

> Student 3: (a) Some kind of plant in mustard family might have evolved with the changes in the condition while sowing the seed. I think the seed grown in the sunny day may grow faster as compared to the seed that would be sown in a shady or a rainy day. If the farmer would keep the plant for more days, the roots may grow longer and wide, which may lead to grow a raddish. In the same way for the

cauliflower or the cabbage the leaves may be grown for a longer time during the generation which may lead to the growth of a cabbage and cauliflower.

Student 4: (a) I think the temperature and climatic conditions may be the reason in variation of the same mustard family and this was the new type of leaves and roots of the same mustard evolved; (b) The selection manipulated by man for his own purpose artificially is artificial selection.

Student 5: (a) During artificial selection the caring and watering would be in a limit so the plant would not extend to root but save itself from winds it would shorten the height of shoot becoming cauliflower or cabbage. (b) Evolution by artificial selection is the changes caused in a species due to the intentional or unintentional intervention of another species.

Although artificial selection is by definition teleological because it relies on people selecting variants for a purpose, Student 5 has extended the teleology to include the intentions of other species and even the intentions of the plants which are evolving. Some non-human species may be able to plan and act intentionally to some extent, but it is certainly an exaggeration to think that a plant or a micro-organism can intentionally evolve.

The students' and teachers' understanding of natural selection was even more problematic. The biggest problem was the teleology which kept creeping into the answers. For example here is how a few BSc students answered the questions, "(c) Explain in your own words how some kind of plant in the mustard family might have evolved through natural selection; and (d) What is evolution by natural selection?"

Student 6: (c) If we go according to Darwin's Natural selection theory, then i will think about "survival of the fittest". But even if a plant of mustard family is able to survive, then it is possible that they can be eaten by some predators or some ants. So, I think the only way that the mustard family plant can survive, is by protecting or preventing itself from any type floods or ants and insects, is by developing a defense mechanism. (d) Evolution which takes place naturally without interpretation of living organisms [sic]

Student 7: (c) Natural forces - calamities/wind, rain, etc, bugs, birds might prefer a particular plant type OR they stronger plants survive the calamities while weaker may perish. The survived ones grow, reproduce & eventually evolve; (d) Nature's forces (Environmetal cond^{n}, animals, etc) select a variety which can sustain in prevailing conditions i.e. grow & reproduce in it. Thus it get evolved.

Solutions: How to address the problems in teaching evolution and natural selection?

In order to address the problems we encounter, we have spent the last three years continuously developing, testing, comparing, and modifying a number of different approaches to teach students and teachers about evolution. Originally we focussed more on doing activities and having discussions in order to understand a broad range of evidence that evolution occurs. Participants did not have much difficulty in understanding and being able to remember and discuss the evidence. In some cases the participants already had a fairly good understanding of the evidence before the workshop or classes began.

However, we found that even at the end of our sessions, many participants still held on to a number of misconceptions and were not able to verbalise a good understanding of the mechanisms of evolution - in particular natural selection. Therefore, we have lately focussed our workshops entirely on understanding evolution by natural selection. As much as possible we use constructivist approaches in which the participants are led through a series of activities and data analysis to construct an understanding of natural selection. **Table 1** summarises the approach that we have developed, in its most recent form.

No.	Activity
1	Observe and draw an individual mustard plant (a species from the Brassicaceae family). Discuss what you learn by the process of drawing and what questions come to your mind as you draw.
2	In groups of 6, compare the 6 different mustard plants you have, and compile a list of similarities and differences. Discuss the similarities and differences and the possible reasons for the similarities and differences.
3	Read and discuss the beginning of the picture book, "What Comes from Wild Mustard?" (Haydock, 2012) in which the development of wild mustard is shown in pictures.
4	Observe some mustard plants at various stages of development, and describe the process of development.
5	Discuss what is science and plan an experiment that can be done to find out whether the size of a mustard seedpod may be due to the seeds. Discuss possible results and conclusions from such experiments.
6	Continue reading and discussing the book, in which the production of different types of crops from the mustard family (Brassicaceae) by artificial selection are shown
7	Write answers to the question, "Suppose there were no people. Could a similar thing happen without people? Without intention?"

No.	Activity
8	Read and discuss the rest of the picture book, in which some possible ways that mustard could evolve by natural selection are shown.
9	Participants write and discuss, "What is the difference between evolution by artificial selection and evolution by natural selection?" Teleology is discussed at length.
10	Simulate the evolution of a population of beetles by natural selection; the participants model birds (predators) selecting beetles (coloured moong) for several generations. Results are graphed, questions are answered and discussed.
11	Discussion on confusions, misconceptions and difficulties regarding evolution by natural selection and final assessment.
12	Discussion on further questions, evidence, and research concerning evolution by artificial selection, including: (a) a discussion of whether our ancestors who developed crops such as cabbage, cauliflower, and radish were doing science; and (b) a discussion of modern methods of plant breeding and the social questions they raise; (c) Who decides?
13	In the end, the following definition of evolution by natural selection is presented and discussed: (a) There is variation between the individual organisms that make up any population; (b) This variation occurs partly because there are random mutations in the genome (differences in the DNA) of individual organisms. These mutations can be passed to offspring; (c) Throughout the individuals' lives, their genomes interact with their environments to cause variations in traits. (The environment of a genome includes the molecular biology in the cell, other cells, other individuals, populations, species, as well as the abiotic environment.); (d) Individuals with certain variants of the traits may survive and reproduce more than individuals with other variants; (e) Therefore the population evolves.

Table 1. Summary of our approach to teach about evolution by natural selection, developed over the course of this study in order to address the problems we found. Activities are shown in chronological order.

Most students are not in the habit of planning and doing experiments in class, and they often do not have a good understanding of the scientific method. This becomes apparent when we ask them to plan and carry out an experiment. They are not in the habit of questioning and critically analysing what they read and what they are told, and looking for evidence based on observing physical reality. This leads to problems in understanding evolution and natural selection. This is why we found it necessary to include activities, experiments, and discussions on variation and similarity, "What is Science?" and artificial selection before discussing natural selection. We have used the same basic approach for students and teachers at all levels from Classes VII to BSc, adjusting the terminology and details as needed. We have assessed the understandings of students and teachers initially and throughout these sessions.

We found that it was beneficial to discuss artificial selection before natural selection, stressing that it occurs by design, and then see if any students could construct a hypothetical scenario by which a similar thing could happen without people and without intention. Younger students who had not previously studied evolution seemed to be better at constructing such a scenario. One Class VII student immediately said, "Maybe a monkey could do it!" Other answers indicated a surprising amount of success in our teaching method, for example:

> It could be possible that wild mustard gave rise to mooli without farmers. The process could have happened naturally or accidentally. It could also have happened due to animals. Some animals must have eaten the seed and the seeds may have stuck to the animals skin. The animal was used as a way of dispersal of seed to long distance. Hence, the undeveloped flowers may have not been eaten and would have reproduced during long periods or the undeveloped flower may have got unusual conditions by which it turned to different types of mustard plants.
>
> The plants which have undeveloped flowers would have accedently be fallen because of the storm and would have been transported to different places and because of rain it would start growing.

In our experience, it is very important to stress the differences between artificial and natural selection, to explicitly discuss teleology, and to avoid using phrases and terms such as, "adaptation", "survival of the fittest", or "struggle for survival". During our workshops, the participants themselves start objecting when someone makes a needlessly teleological statement like, "The plant's roots try to find water", or "The plant knows.." (Such a discussion among BSc students led to the question of whether plants have "atma". It was pointed out that there was no physical evidence for this. Still, one student insisted that he knows plants have "atma" on the basis of his intuitive inner beliefs - and that authorities have told him.)

Why do people think teleologically?

Why is it that teleological thinking in biology is so widespread? Some say that teleology is intuitive, and that is why even young children have a natural tendency to think teleologically (Kelemen, 1999; Kampourakis et al, 2011). But perhaps this is being unnecessarily determinist. More likely, teleology springs from our rational efforts to understand and explain our world. In order to explain the unknown, we make analogies with what we know - and one of the areas we know best and are most concerned about is ourselves. This rational tendency towards egoism is one factor that contributes to our tendency to think teleologically. One of the defining characteristics of humans is our ability to plan and do things intentionally. We understand other organisms, other processes, and other things by comparing them to ourselves and our own behaviours and processes. Therefore, by analogy we suppose that other organisms also do things intentionally. This is not intuition, because it is based on reasoning, although the reasoning may not always be very conscious or explicit.

Another factor that may contribute to our tendency to make teleological explanations is that such explanations are simpler. It is simpler to think that animals got wings in order to fly than to think that in a population of mostly wingless animals some individuals just happened to have heritable wings, and then they found that they could use wings to fly, and then the ones with wings survived and reproduced better than the ones without wings. Reality is complicated, interconnected, and difficult to understand.

Our work confirms that the non-teleological process of evolution due to natural selection is more difficult to understand than the teleological process of evolution due to artificial selection, with which we are more familiar. Uneducated farmers understand evolution by artificial selection because this is the process that they use to develop crops and domesticated animals. So it is easy for a farmer to suppose that other physical processes are also teleological. As we have seen, many Class VII children in our workshops manage to understand how artificial selection works. By simple analogy some students then suppose that a plant wants to produce thorns so that cows will not eat it, just as a farmer wants to produce plants with larger fruit so that she can eat it.

Another reason why people think teleologically is that in India, as in many other parts of the world, people tend to have an idealist way of thinking about the world, thinking that abstract ideas, spirits, 'atma', or some kind of god or gods are basic causes of physical reality. Some even go to the extent of believing that the physical world is only a figment of our imagination. Thus, idealists will tend to look for non-material causes. They will be more likely to think teleologically, expecting that things are the way they are because they were designed for some purpose rather than because they are the result of a physical process. Why do people have idealist ways of thinking about the world? Perhaps it is a dominant form of cultural indoctrination, which helps to keep order in the social system because it encourages faith in authority rather than questioning authority.

This is in contrast to a materialist way of thinking about the world, in which matter is basic and ideas are considered to be the products of physical processes. The natural sciences require a materialist way of thinking since they are concerned with finding material causes for physical reality.

Of course, many people are dualists, believing that there are two separate, non-interacting worlds - one of physical reality, and the other of ideas or spirits. A dualist may be able to understand that evolution occurs due to the physical process of natural selection, while still adhering to non-material explanations for other processes. Conflicts may arise when trying to distinguish between whether a physical process is due to material or non-material cause.

For example, it is not uncommon for Hindu fundamentalists, and even those who are not so fundamentalist, to pride themselves in claiming that Hinduism is 'scientific' and rational. Not only do they believe that evolution has occurred, they also believe that the ancient Hindu sages already knew about biological evolution - and they also knew much more:

> The standard sequence of biological species that modern biologists have inferred from the fossil records spanning long stretches of time, is accepted as a “lower-level truth” already known to ancient Hindu sages who are said to have “surpassed” it in favor of the “higher” truth of spiritual evolution. (Meera Nanda, 2010)

This view was expressed by numerous people in emails received in response to the Hindu article (Haydock, 2009).. Here are two examples:

> What the bio-scientists today call Gene factor, is the jiva-atman in the Indian belief system. Life-giving cell atman is trans- migratory among different physical forms - monkeys, snakes, birds, bees, animals and humans - and even trees.
>
> well I am not scholar of Hinduism but one of sacred writing in Bhagwat geeta it has been described that what had happened and what is happening and what will happen is happening for good.(jo hua who achha

> hua jo ho raha hai who bhi ache kay liye ho raha hai aur jo hoga who bhi ache kay liye hoga)…I take this Jo hoga (happening) as Darwins theory.

They are actually not understanding what is biological evolution or what is natural selection, or what is science. They are using pseudo-science in order to prove the validity of religious beliefs that are based on faith, rather than on observing physical reality, questioning, analysing, and experimenting. It is interesting to note the contrast with western non-scientists who use religious beliefs to 'disprove' science. In neither case is a scientific method being understood or followed.

Here is another example, this time by an idealist engineer teaching at a major university:

> Early on in the quest for science, we teach the students to study the functions and limitations of the instruments used, so as to gauge the reliability of the observations.
>
> But the curriculum most often falls on its nose with a thud: Has the student ever been taught to introspect and know the functioning and limitations of one's own intruments of perception?
>
> Western system of scientific enquiry is completely flawed. Should we turn a blind eye to the infinite knowledge and wisdom garnered by the sages of yore and infused into our traditions and philosophy; and ape the johny come of late western system??!!!!
>
> Be one to awaken the sense perceptions of the young and eager and lead them on to true knowledge.

This kind of thinking may appeal to a post-modernist relativist who believes that scientific and non-scientific explanations are equally valid and a scientific method should not be used to investigate the infinite knowledge of the sages of yore. We find this kind of thinking creeping into the thinking of some educationists:

> I find that students sometimes accuse teachers who propose that science is the only way of knowing, the only legitimate tool for answering any question, of scientism—inappropriately privileging science and scientific methods above all else. The criticisms of these students seem to be appropriate. (Smith, 2010)

We think this is an odd position for a science educator to take. We would expect that a science educator will use scientific methods.

Educationists need to be aware of the differences between indoctrination and education. Both indoctrination and education result in changes in beliefs - various kinds of beliefs. But the process of indoctrination is based on accepting authority, whereas science education is based on learning through questioning authority and observing physical reality. However, we should not deceive ourselves by thinking that science education can be objective. Teachers as well as students do have particular points of view and ideologies, depending on their backgrounds, past experiences, circumstances, and environments (Matthews, 2009). It will be better to be aware of our points of view and the reasons for them.

This is not to say that a teacher should insist that students should not be religious. If we use a scientific method to analyse why people are religious, we will see that there are good reasons for religion:

> Religion is, indeed, the self-consciousness and self-esteem of man who has either not yet won through to himself, or has already lost himself again. But man is no abstract being squatting outside the world. Man is the world of man—state, society. This state and this society produce religion, which is an inverted consciousness of the world, because they are an inverted world. Religion is the general theory of this world, ... its moral sanction, its solemn complement, and its universal basis of consolation and justification.
>
> Religious suffering is, at one and the same time, the expression of real suffering and a protest against real suffering. Religion is the sigh of the oppressed creature, the heart of a heartless world, and the soul of soulless conditions. It is the opium of the people.
>
> The abolition of religion as the illusory happiness of the people is the demand for their real happiness. To call on them to give up their illusions about their condition is to call on them to give up a condition that requires illusions. (Marx, 1844)

Our goal as science educators is to increase scientific temper. We teach and learn about evolution and natural selection not just in order to examine and understand life, but also in order to change our world. Even if we find that religious fundamentalists are interfering with the teaching and learning about evolution and natural selection, we cannot demand that our students completely abandon religion. Religion may be very necessary for them at present.

It is interesting that although late in his life Charles Darwin was not religious, he took a position which is not conflicting with the ideas expressed in the above quote.

> It seems to me (rightly or wrongly) that direct arguments against Christianity and Theism hardly have any effect on the public; and that freedom of thought will best be promoted by that gradual enlightenment of human understanding which follows the progress of science. I have therefore always avoided writing about religion and have confined myself to science. (Darwin, 1880)

Note that this approach is quite different from the approach of Smith, who seems to be afraid to be too scientific and afraid to "privilege ... scientific methods above all else". Should educators teach how through intuition, introspection, or faith in authority we can know more than we can find out through science? It will be better if educators aim for education rather than indoctrination. We suggest that the words of both Darwin and Marx can guide us in our approach to leaching and learning about evolution and natural selection.

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Fractions They Know - Fractions They Study

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Traditionally, the topic of fractions has been considered to be one of the most difficult areas in primary school mathematics. Many studies suggest that the fact that fractions are multifaceted and include different meanings or "sub-constructs" is one of the reasons for this. It was been seen that usually the approach to teaching fractions has been the part-whole meaning or sub-construct of fractions. The Maharashtra State Board mathematics textbooks deal with only the part-whole meaning of fractions in primary grades using area model. The aim of our study was to observe student strategies and responses to situations where various meanings of fractions which were not formally taught to them were used. The study was done with 35, Grade 6 and Grade 7 students from a remote, rural government school. The final task-based analysis of responses showed very surprising results. Among all the sub-constructs, the percentage of correct responses for the part-whole sub-construct which was formally taught to them from Grade 3 to Grade 5 was lower than the percentage of correct responses for the other sub-constructs. One of the reasons can be that the part-whole meaning is often misinterpreted as a 'counting' exercise. Another reason can be that a circle or a set of squares are abstract as compared to situations in which there is sharing of rotis or halving an quantity.

Introduction

Teaching and learning of fractions have been one of the most problematic areas in primary school mathematics. Many studies suggest that the fact that fractions are multifaceted and include different meanings or "sub-constructs" is one of the reasons for this. There has been a lot of research done about the 'best' approach to teach fractions. In the Indian context the work done in HBCSE and Ekvalya (Naik & Subramaniam 2008, Subramanian, Subramaniam, Naik & Verma 2008) suggests that the sharing and measurement approach to teaching fractions may be effective.

Traditionally the approach to teaching fractions has been the part-whole meaning or sub-construct of fractions. The same was observed in the analysis of Maharashtra mathematics textbooks done by researchers. The Maharashtra State Board mathematics textbooks deal with only the part-whole meaning of fractions till Grade 5. In Grade 3 when fractions are introduced, the textbooks only deal with the area model of part-whole. A similar approach is found in the Grade 4 textbooks. The measure, ratio, operator and quotient meanings of fractions are introduced only after the fifth grade. However, children deal with situations from their daily lives involving ratio, measure, quotient and operator meanings (sub-constructs) of fractions and use their own strategies in dealing with these situations when they involve simple fractions.

As a part of the study, a test was developed with the purpose of checking the familiarity of the students with various meanings of fractions. The tasks in the test were divided into five groups of tasks for each sub-constructs of fractions. Each group had a series of tasks most of which were connected to each other. There was an attempt made to phrase most of questions in a way which would sound familiar to the students.

The study was done with 35, Grade 6 and Grade 7 students from a remote, rural government school. The school is located in the Wada Tehasil of Thane district, Maharashtra. Most of the children were first-generation learners. Most of the parents were farm-workers and belonged to the lower socio-economic group of the society.

Theoretical model of five sub-constructs of fractions-constructs

According to Charalambous & Pitta-Pantazi (2007), part whole or the partitioning is most basic for developing understanding of the other sub-constructs of fractions. The ratio construct is considered the most natural path to promote the concept of equivalence and the process of finding equivalent fractions. The operator construct is regarded as helpful for developing the understanding of multiplicative operations on fractions. The measure construct is regarded as helpful for developing understanding additions of fractions.

Definitions of sub-constructs:

- **Part whole construct** : 'A part whole comparison designates a number of equal parts of a unit area out of the total number of parts into which the unit is divided.' (Lamon, 2005, p 125).
- **Ratio**: 'This construct conveys the notion of comparison between two quantities, it is considered as a comparative index than a number' (Charalambos 2007). 'A ratio is a comparison of any two quantities. A ratio may be used to convey an idea that can't be expressed as a single number' (Lamon 2005, p 182).
- **Operator**: 'The operator interpretation of the rational number, we think of rational numbers as functions. In this role rational numbers act as mapping, taking some set or region and mapping it onto another set or region' (Lamon 2005, pp 151).
- **Quotient**: 'Within the quotient sub-construct, any fraction can be seen as a result of a division situation' (Charalambos 2007).
- **Measure**: 'A rational number measure directed distance of certain points from zero in terms of some unit distance' (Lamon 2005, p 170).

Tasks were developed so to check the familiarity of students with the above mentioned sub-constructs of fractions.

About the sample and the test-administration:

The sample we chose was from the government Marathi medium school (Zilla Parishad School) in Wada block, which is remote area of the Thane district in Maharashtra state. All students are from lower socio-economic background. Parents of most of the students are farm labourers and very few of them own land. All students from the sample help their parents in their work.

These students go to forests in groups on holidays to gather 'gum', 'jaamoon', 'mangoes' and other eatable things. When they gather together, they distribute everything among them. Many of them are living in very small hamlets of 2 to 10 huts in forests of the periphery of the school. The 'government ration' shop and other shops are situated in the same village where they go to school. Hence they have to shop for many of their family needs. Through the all the above activities, students encounter and use fractions in their daily lives.

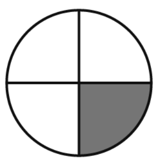
The initial plan was to administer the test to students of Grades 5 and 6 but during the pilot one of the researchers felt that while Grade 6 and 7 students were quite comfortable with the tasks, Grade 5 students were not and they found the tasks difficult. Hence it was decided to administer the test on Grade 6 and Grade 7 students. There were 35 students in the sample (17 from Grade 6 and 18 from Grade 7). The mode of response to the test was very flexible, students could answer by writing in numerals, in words or drawing pictures. The only condition was that they had to give reasons for all their answers. Very few of them were unable to write by themselves, thus one of the researchers helped them to write their responses. After the test the one of the researchers interviewed the students on their responses.

Tasks' analysis:

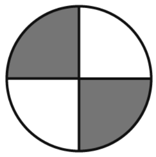
There had to be a wide variety of tasks related to the part – whole construct in the textbooks of Grade 3 to 5 of S.C.E.R.T. Maharashtra as this is the only sub-construct dealt with till Grade 5. Comparision, addition and subtractions with equal denominator and non–equal denominators, equivalance and all other operations on fractions are covered only in Grade 5 (Subramanian & Verma, 2009). When we went through textbooks of S.C.E.R.T. Maharashtra state we found the same.

There are five groups of tasks for each sub-constructs of fractions, viz. A, B, C, D and E. Each group has a series of tasks which are interconnected with each other. Due to the constraint of space, we will discuss tasks for only two sub-constructs in this paper, the Part-whole sub-construct and the Quotient sub-construct. The first group of tasks was to check students' understanding of the part-whole sub-construct.

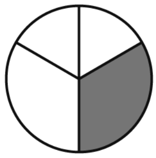
1. What part of the given figure is coloured? Write in fractional form.



2. What part of the given figure is coloured? Write in fractional form.



3. What part of the given figure is coloured? Write in fractional form.



The second group of tasks was specially designed to see the students' understanding of the 'quotient' meaning of fractions. There are two daily life tasks in this group of questions. For each question space for drawing the picture was given. But there were not explicit instructions given to draw the sharing as we wanted to give the students the freedom to choose.

1. Three children shared four chikki equally, what will be share each? Write in the fractional form.
2. Three rotis are divided equally among four children, What will be share of each? Write in fractional form.

Data Analysis:

The data was collected to meet the needs of objectives of our research. The quantitative data was collected from the previously mentioned school.

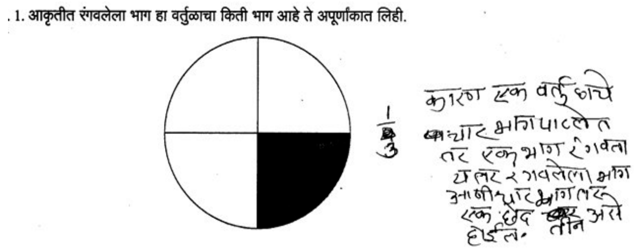
Name of the construct	% of correct responses
Quotient	45.71%
Operator	36.19%
Measure	21.14%
Ratio	15.71%
Part whole	14.29%

Table 1. The percentage of the students, who have responded correctly for different sub-constructs of the fractions.

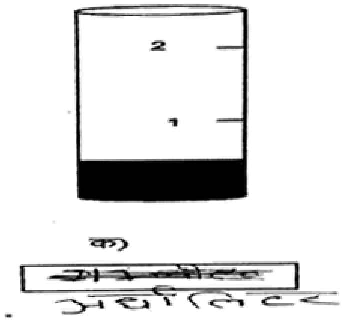
This table shows the percentage of the students out of 35 students who have responded correctly for different constructs of the fractions. The percentage indicated is the percentage drawn based on the collective correct responses in respective construct of the fractions.

Case-Study of a student's familiarity with different meanings of fractions.

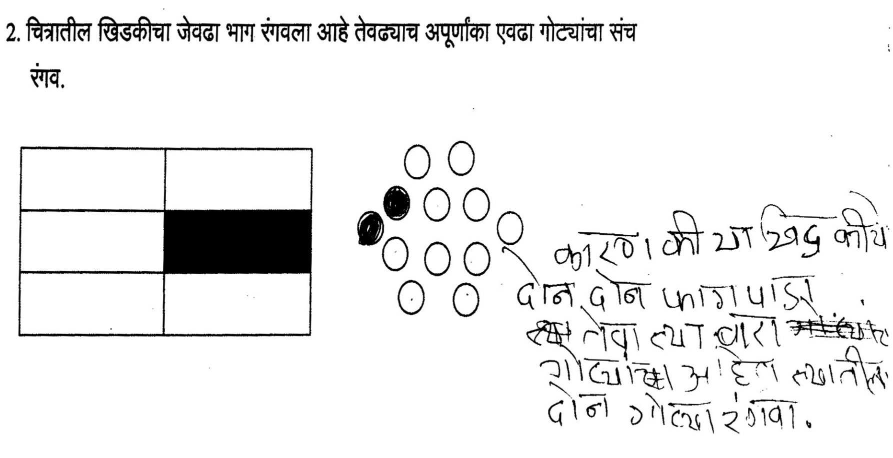
This Grade 6 student was asked to write the name of the coloured portion of the circle in the fractional form. The student responded said it was 1/3, and the reason given by him was that the figure is divided into four equal parts and the out of those three parts are not coloured and one part is coloured so the name of the coloured portion is 1/3.



The same student responded for a question on measure construct in the following way. The student was asked to write the amount of water in the jar.



He answered this question correctly as '*half litre*'. One of the reasons why the student was able to do this question might be that he might have seen measuring cans being used in his everyday life. Another reason can be that though he understands fractions, he has difficulties in the fraction-notation.



The question was, "Colour the marbles in the same fraction as the coloured windows" The student answered this question correctly and gave the reason as, "*Because, if the windows are divided in two parts and there are 12 marbles so 2 marbles are coloured*". This reason given by the student suggests that he has an understanding of equivalent fractions.

Findings

- The 'quotient' is the sub construct with which students encounter very often in daily life situations (Subramanian & Verma, 2009, p. 139). This is reflected in our work. Students on whom we applied these tasks are from that backgrounds in which they go to forests to get mangoes, or they buy something from shop to eat (like chikki, bread, cake, etc because many of them don't have sufficient money to buy such things but still they want to eat) and share these thing with each other. This practice of sharing is also very common in the house too (sharing rotis). Thus they are very familiar with the sharing situation. Out of all those who have responded correctly for the sharing situations tasks, few of them described the share in the form of number and represented it as fractions but many of them drawn the pictorial representations for the sharing situation and when one of the researcher asked them personally in the interview about the response almost all of them said one of the following;

i. "one whole and one piece of one third size" for first question while for second question some said "one half piece and one quarter piece", some said "three will get piece of ¾ size and one will get three pieces of quarter" or some said
ii. "each will get three pieces of quarter." In this case they have partitioned the whole into four pieces and then distributed three pieces to all which shows somewhat measure approach of fractions.

The data also suggests that the operator meaning of fractions is also familiar to them especially the two operators we had selected were very familiar namely- half and quarter. This showed the familiarity of students with the operator meaning of fractions and the two fractions used. As the third fraction we selected – 1/3 was not very familiar and hence the percentage of correct response for this fraction was much lower than others.

- The moderate correct responses to the measure construct suggest that this construct is not frequently used in their daily life. Though some of them go to government shops to buy kerosene once or twice in a month.
- The part whole construct is formally introduced in the text books from Grade 3. But the percentage of correct responses to the tasks for this sub-construct was the lowest among all other constructs. This might be because they were unable to connect to things like dividing a circle or square in equal parts. It is interesting to see that the sub-construct which is the only one taught formally to them had the lowest correct percentage.
- In summary, this exercise may conclude that students can work with some of the sub-constructs of fractions without any formal introduction to them. And that they construct their own strategies to tackle these tasks. Our study suggests that students might find formal fractions more accessible if introduced through sub-constructs of fractions they can relate to. (NCF 2005).

Acknowledgements

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Exploring Phenomenography-Language Interface in Science for Conceptual Transformation during Teacher Preparation

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All external forms of knowledge representation (images, language etc.) are subject to i*nterpretation and there could be several factors that shape this interpretation. While examining the role of language (as a form of knowledge representation) in knowledge construction, this paper explores the interplay between language and phenomenography and shows how recognition of this interplay could be a possible way to facilitate conceptual transformation in future teachers.*

Introduction

Knowledge of the world is externally as well as internally represented. Where as internal representations are personal and subjective and would perhaps be more appropriately described by such words as 'conceptions', 'mental constructs', 'ideas' or 'visualisation'; external representations are depictions used to convey the 'shared conceptual understandings' in an area. External representations although open to subjective interpretation are objective entities. In this paper the term 'representation' is used to refer only to the 'external' representations'. Language as a way to represent the world subtly encodes various understandings related to it and phenomenographic research tradition informs us that there are varied but a limited number of qualitatively different ways in which a phenomenon can be understood (Cope et. al., 1996). This paper attempts to examine the two-way relationship between subjective experiences and language used to convey these experiences and illustrate how helping future teachers reconfigure phenomenography-language relationship can actually give insightful clues to conceptual transformation.

Role of Representation in Science

Representation refers to the process of conveying shared understandings about the world through different means i.e presentation of the thoughts employing different modes of communication. There are different 'generic modes' in which external representations to express internal visualisations could be constructed: gestural, concrete/material, visual, symbolic and verbal (Gilbert and Boulter et al., 2000). These representations though intended to help in construction of shared knowledge can also hinder it, if not interpreted in the intended sense. Glasersfeld (1987) emphasises that no representation represents by itself-it always needs to be interpreted by an interpreter. In other words the semiotic modalities (multi modal representations) are not sterile means of communication that are passively received. Rather, they are actively engaged with, mentally worked upon and internally negotiated. Sarukkai (2007) offers a binary of 'context of practice' and 'context of communication', wherein the former pertains to the way science is done while the latter relates to the way science gets talked about. However, these two aspects are not seen in opposition to each other because we must begin with examining scientific practice and then look at ways in which these practices get communicated. Representations such as images (pictures, diagrams, drawings etc.) need to be subjected to 'transformational reasoning'(Ramadas, 2007) i.e transformation of representations into meaning making entities by identifying and drawing upon various factors that mediate between external representation and the knowledge it encodes. The idea can be fruitfully extended to linguistic representations as well.

Role of Language in Science Communication

Role of language in knowledge construction has come to be widely appreciated. The Vygotskian viewpoint which asserted that attribution of appropriate meaning to a word actually amounted to acquisition of the concept denoted by that word, led to a wave of rethinking on the role of language in learning. Language cannot be considered a 'neutral' means for communicating personally and internally generated thoughts but actually, language provides the tools through which those thoughts are first rehearsed on the inter mental plane and then processed and used (Leach and Scott, 2003). In sciences, words of everyday language are often assigned special meanings, and language and concepts are significantly interlinked. The area of mechanics is full of terminology that can be quite difficult to comprehend and we may often be required to reframe certain terms and terminology. For instance, the term rotational inertia' conveys more meaning than 'moment of inertia'. Throwing and dropping a ball may mean the same in everyday language but have distinct connotations in the field of physics. Touching upon the dichotomy of language, Frank (2004) says that there are two types of statements-'observational statements' which contain the words of everyday life like hard, green etc. and the axioms of specific disciplines like geometry, mathematics etc. that contain specialized verbal symbols like circle, acceleration and so on. The two vocabularies being incommensurable, a statement of the second type can never be confirmed or refuted by the first type. In addition to these two types of statements, scientists therefore have to make use of the third type by which the language of abstract principle can be translated into the language of observation. To make the point that there is a need to go beyond semantics and take into account the syntactic considerations while examining the role of language in learning physics, Touger (2000) cites the example of Newton's first law of motion . Newton's first law of motion states: Every body continues to be in a state of rest or of equal motion unless it is compelled to change that state by forces acting on it. If the last phrase of this statement is reworded as '…by forces impressed upon it', this would cue the reader to the existence of another entity which is impressing the force. Similarly, Newton's third law of motion; 'To every action there is an equal and opposite reaction' makes more sense when stated as: 'whenever one object exerts a force on a second object, the second object instantaneously exerts an equal and opposite force on the first object.' Brooks (2006) emphasizes that to appreciate how learners construct meaning, it is extremely important to be perceptive to what actually the physicists' language encodes. Language is one kind of many representations of the physical models that physicists construct to explain reality and it is important to be sensitive to its limitations because the linguistic representations can sometimes completely contradict the idea contained in the model. This can be illustrated by taking the example of 'heat'. Frequent references to heat as a substance in texts as well as in language (amount of heat transferred to a system, water rejects heat….etc.) can prevent the students from recognizing it as a process. Stating that 'force causes motion' instead of 'force causes acceleration'(Arons,1997 p.73) can lead to the conception 'constant motion requires constant force'. In the context of optics also, language poses difficulties. As Galili and Hazan (2000) point out many linguistic constructions do not conform to present-day scientific knowledge. They give examples of phrases such as `her eyes shine', `his face radiates light', `she casts a glance'and `the tree casts its shadow' which do not resonate with the scientific understanding. Even in ancient Indian mythology, phrases such as 'divya drishti'(divine sight) somehow reinforce the primitive idea of 'active vision' i.e. something emanating from our eyes to enable vision. Development of language, having preceded our scientific understanding, has been largely guided by our intuitive, subjective and socio-cultural influences. Phenomenography and language then interact curiously to convey ideas that may contradict the scientifically held views.

Teachers as learners

That teachers' conceptual understanding is itself deficient on many counts has been widely highlighted in the research literature. The need to help teachers or future teachers revisit and review their understanding of fundamental ideas of their respective disciplines is therefore imperatively felt. Teacher preparation courses are an appropriate juncture to undertake this exercise as by virtue of their purpose and nature they can afford the future teachers an opportunity to engage in such exercises as reflecting upon the nature of their discipline, taking a top view of knowledge free from the stress of proving themselves at examination and thereby cultivating meaningful subject matter related insights in the process.

Accessing Future Teachers' Ideas

As an initiation exercise for studying future teachers' (f.t.s) ideas in optics, a few questions were put to 13 students enrolled in a one year teacher preparation programme offered to graduate/post graduate students. All these students had opted for physics as one of their teaching subjects. Some of the questions that were asked and the responses that were received are presented in Table 1.

Question	Nature of response	No. of f.t.s giving this response	Analysis
What is Light?	Light described as energy/phenomenon. Light described as object	11 2	A major majority of the future teachers described light as a process.
How would you explain this phenomenon to students to be initiated into optics?	Light referred to as event/energy/phenomenon Light referred to as a 'thing'.	6 7	Many f.t.s who did describe light as energy initially may not really think of it so.
Do we see light?	yes no	3 10	Visibility/invisibility of light is a perplexing phenomenon
How do we differentiate between a light bulb that is switched on and one that is switched off?(This question was posed to the 10 f.t.s who said light was invisible	We see the light particles. Light is invisible but becomes visible after getting reflected off an object. We see the gas particles that are present in the bulb. We see bulb filament, not llight	2 1 2 5	Of the 10 f.ts who said that light was invisible, at least 3 gave counter responses by suggesting that light 'particles' or only 'reflected light' was visible.
Question	Nature of response	No. of f.t.s giving this response	Analysis
You may have observed at the colour of an object may appear different under conditions(e.g. under different lights). Can we then say that every object has a true colour?	Yes/Yes because colour of object remains same/yes but true colour is seen in white light No/No,colour is subjective	8 5	!Many of the future teachers think of colour as an inherent property of an object.

Table 1. Questions and the responses

The table shows that future teachers' deep seated notions may be more difficult to unearth as a long term engagement with the subject matter prepares them enough to give well tutored and conceptually sound answers in response to standard questions. Posing questions that require free and spontaneous articulation may be more useful in examining how they think about a particular phenomenon. So, while the question '*What is Ligh*t?' was asked to see how the students ontologically classify light i.e. as a substance or a process, asking them how they would explain this phenomenon to students who have to be initiated into the study of optics at school level, was just another way to assess the ontological status assigned to light by the future teachers. Whereas the question 'what is light' evoked standard response, putting the question the other way encouraged the subjects to reframe or reword or elaborate on their understanding. Their latter utterances being self generated are more likely to be indicative of their ontological assumptions.

Language-Phenomenography Interface

Language bears a two way relation with phenomenography which has 'human experience' as its subject of study. While using language to assign meaning to the subjective experiences, differences may creep into the semantic and intentional meaning. Also, the descriptive terminology used to convey a phenomenon can also subtly influence the subjectivist interpretation of the phenomenon in question. A phenomenographic exploration of learners' ideas in an area entails describing the conceptions, reflecting on the nature of conceptions and figuring out the possible factors that have led to their formation. The above table points to two alternative ideas commonly demonstrated by learners viz. 'light is a substance' and 'colour is an inherent property of objects' and the perplexity about visibility or invisibility of light. To be able to address these ideas, we need to closely scrutinise and analyse the difficulties that learners face while reasoning about the optical phenomena. The difficulties clearly arise from subjective experiences that our language subtly encodes, thus reinforcing them. This is best illustrated by the confusion around visibility/invisibility of light. Before we decide whether or not we 'see' light , we need to clearly spell out what we mean by 'seeing'. Obviously, we do not see light in usual sense of the term, like we see ordinary objects i.e. light falls on the object, gets reflected into our eyes and the image of the object gets formed on our retina. Human eye is nevertheless sensitive to the presence of light. It is relevant to ask what could be the reason for our eyes to be sensitive to a particular range of wave lengths. Scientists investigating this question forward different kinds of explanations. One probable answer is that since radiation is the maximum in this range, the human eye has evolved to create light censors suited or adapted to this particular range of electromagnetic radiation (Bõchnicek,2007). At this juncture then, we will have to make a distinction between 'seeing' and 'sensing' and then we may be able to say that though we are able to sense light, we do not see it. Kirk (1994) discusses Goethe's phenomenological optics and highlights how phenomenology being generally relevant to all sciences assumes particular importance in the case of optics because the human interaction with the phenomenon is constitutive of its science. , Anderberg, Alvegard and Johansson (2009) identify three approaches to students' use of language in understanding subject matter: the cognitive, the socio-cultural and the phenomenographic. The social meaning is derived from the social language, the cognitive from the concepts that form a part of the individual conceptual knowledge system and the phenomenographic meaning is based on the most immediate context of the learner and the way the individual relates to a part of the world. So while the meanings given in cognitive and/or social languages are generalized and stable, the individual contextual meanings are fluid. It is the phenomenographic meaning of an expression that requires investigation so as to be able to relate with the learner because often the meanings assigned by students to certain expressions do not correspond to those expressions in the subject matter theory.

Considerations for Conceptual Transformation in Teachers

It may be argued that conceptual transformation considerations for teachers or future teachers would differ considerably from those of young learners. Teachers' prior knowledge that needs to be taken into account comes not only from their everyday experiences but more from the interplay between intuition and formal instruction received during school and college. A viable way to help teachers in the process of re-conceptualisation is to evolve a discourse that revolves around nuances of represented knowledge that encourages them to re-examine and re-configure represented knowledge. Reconfiguration implies reflecting upon the various aspects of represented understandings primarily with a view to recognise their limitations and let this recognition inform the reasoning about the represented phenomena. This is facilitated by starting out with a certain form of representation and raising questions that bring out the un stated and therefore lesser understood aspects of that representation. Cope et. al. (1996) point out that as a teaching technique, phenomenography can make students aware of their own and others' conceptions of the same phenomenonon.

Reconfiguring Represented Knowledge

By way of illustrative example, we take up one of the ideas highlighted above which is –'Colour is an inherent property of an object'. As a part of a wider study, the prevalence of this idea was investigated among 56 future teachers enrolled in teacher education courses across three institutions. This interventional study, founded on a pilot exercise described earlier in the paper, investigated the possible prevalence of 27 variant conceptions (conceptions that differ significantly from the scientific view) in optics among future teachers. The study was premised on the view that encouraging the future teachers to reflect on the nature of their own conceptions and on the factors that have facilitated their formation, can encourage them to significantly recast these. Closely considering the nature of these ideas and reflecting upon their possible causes led the researcher to develop 5 modules that were titled as follows. (I) **Self, sight and vision**: In this module an attempt is made to assign an active role to the eye in the process of vision by consistently attracting the attention of the student teachers to its presence. (II) **Images in Optics**: This module intended to help future teachers appreciate the limitations of images such as diagrams, sketches in conveying the shared scientific understanding of the optical phenomena. (III) **Words and Meanings:** 'Words and Meanings' makes an attempt to encourage the future teachers to reflect upon the language of 'optics'. (IV) **Building Understandings I: Multiple viewpoints:** This module made an attempt to *juxtapose the multiple explanations of the optical phenomena (ray, wave and quantum) as they have historically evolved to help future teachers access knowledge from different viewpoints. (V)* ***Building Understandings II: Exploring the nature of reality:*** *In this module, an attempt was made to wean the students away from classical thinking by referring to the experimental observations that are inconsistent with the classical world view.*

Interestingly, half of the future teachers (28) who participated in the study demonstrated an indicative evidence of subscribing to the conception: 'Colour is an inherent property of an object unaffected by external factors' while the rest 28 gave an indicative evidence of subscribing to the shared conception.

An analysis of the conception leads us to attribute its formation to the following causes:

- Insufficient recognition of the role of eye in colour perception and of the fact that the property 'colour' exists because of our being able to perceive it failing which it would carry no meaning , no matter what the properties of an object or the wavelength reflected off it may be.
- Linguistic usage that ascribes colour to objects rather than projecting it as a perceived phenomenon

As an attempt to address the situation, the questions pertaining to the role of eye and the linguistic limitations in conveying the phenomenon were raised during the course of modules titled 'Self, Sight and Vision' and 'Words and Meanings' respectively. The queries were meant to persuade the future teachers to review their ideas. The future teachers were asked to write their thoughts as they proceeded so that it was possible to trace their thought process and also because this kind of explicit rethinking would facilitate clarity of thought and a meta awareness of one's own perceptions. The queries appeared in a specific context and drew attention to the specificities mentioned above. Given below is an excerpt from the module 'Self, Sight and Vision'

> ***Colours and Us*** *As we know, we are able to perceive different colours because our eyes happen to be sensitive to a particular range of wavelengths of electro magnetic waves .*
>
> *The retina of human eye has two types of cells-one that are light-intensity sensitive or the rods and the other that are colour sensitive or the cones. The three kinds of cones are called red cones, green cones, and blue cones in accordance with the wavelengths of light that they are sensitive to.*
>
> *The eyes of most animals are not sensitive to colours and some cannot differentiate between colours. Our eyes are sensitive to 7 colours. We have named certain wave lengths as colours because of the fact that our eyes just happen to be sensitive to these. So colours have to be looked upon as a purely subjective experience. 'Black' or 'white' are not strictly colours though we do talk of them so in our everyday language. If there were some other species whose eyes were sensitive to other wavelengths, would the 'true' colours of those objects then change or if the whole of humanity were to collectively lose sensitivity to a particular wavelength over a period of time, what would you then say about the 'colour' of these objects? Now think, can the colour of an object be thought of as a property of the object?-*

The following paragraph taken from the module 'Word and meanings', by asking the future teachers to reframe a statement seeks to draw their attention to the clear inadequacy of our everyday language in conveying scientific understandings.

> When we say 'this car is red', we attribute the property of red to car but is the colour an inherent property of an object? Reframe this statement in such a way that the property 'red' is dissociated from the object and comes across as a perceived phenomenon.

Findings and Discussion

Each *developed module addressed a specific aspect of the nature of knowledge in optics. The writing style was interactive and the participants were expected to respond to certain questions as they proceeded with their work. The key features of the responses received to each of the query were identified. On the basis of whether or not these responses resonated with the primary objective of that module, they were categorized as positive or negative.* Of those 28 future teachers who indicated the presence of the conception, 'Colour is an inherent property of an object unaffected by external factors' 16 (57.1%) gave an indicative evidence of having modified it to the shared conception that 'The colour of an object ultimately depends upon the receiving system i.e. the eye' post intervention. The positively indicative responses to the first query cited eye as the main factor in determining the colour of an object. The positively indicative responses to the second query were of two types: Our eyes see the car as red or we perceive the car as red (the car appears red to us). Of the 16 future teachers who modified their alternative conception, 14 responded positively to both the queries while two responded positively to one of the two queries. Of the 12 participants who retained their alternative conception 8 performed positively on one of the two facilitative queries while the remaining 4 did not perform positively on any of the two queries. That the given treatment of the subject matter was able to help more than half the future teachers re-visit their alternative notion does open up a helpful path to bring about conceptual transformation among prospective teachers. It is to be appreciated that the study was conducted on a limited sample and did not aim at generalisation but only at gathering helpful hints regarding ways to help future teachers review their alternative understandings of optical phenomena. Even though 16 of the future teachers showed a visible difference in their way of reasoning about the optical phenomena, it may not be feasible to say whether conceptual transformation has 'occurred' or 'not occurred' and a deferred post interventional assessment is warranted. Also, despite the teachers giving the evidence of subscribing to the scientific idea in a given situation, there can be no absolute certainty that they would invoke the relevant reasoning in new situations as their views may be context dependent. We must as well consider that certain conceptions may be more readily amenable to revision through this kind of treatment of the subject. In spite of these obvious cautions that need to be exercised while interpreting the finding, the results nevertheless do open up a new window to the nature of interactions that could persuade mature participants to put their ideas and understandings in a fresh perspective informed by a sophisticated hind sight.

These findings provide some useful pointers for the process of teacher preparation. Teacher preparation courses will need to take on a more substantive responsibility for enhancing the conceptual understanding of future teachers. Subject matter studies need to be strengthened in a manner that would help future teachers re-explore fundamental school concepts qualitatively. The focus has to be on development of qualitative insights that is neglected in regular graduate and under graduate courses, where the emphasis is more on enhancement of quantitative skills and clever problem solving. education curricula should aim at incorporating domain specific meta discourses that help future teachers review their own conceptual understandings.Ample research evidence is now available on learners' ideas and cognitive difficulties associated with various science concepts. This should lead to formulation of content specific theories which in turn should feed into the pedagogy courses.

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Representing Change Using Concept Maps

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While concept maps have been quite extensively used to represent static descriptions, it has not been used for its full potential for representing changes or processes. We propose a template and a limited set of linking phrases for representing change, with partial amendments in the concept mapping technique and the CmapTools. Usually, a process is represented in a object-centric manner specifying the object's role in it. In this proposal, we suggest a process-centric strategy with certain heuristics for representing processes. Considering the view that a process is a name to a change of state of an object involving time, sequence, causes, we make necessary proposals to the vocabulary and the form of representing a process. We end with a discussion on implications of this proposal to science education and concept mapping in general.

Rationale

It may not be a hyperbole to say that most important breakthroughs happened in the history of science when scientists found a way of representing the changes or cracking the mechanisms of how things change. The study of *motion, chemical change, circulation, evolution, plate-tectonics* are a few examples of phenomena that have led to breakthroughs in science. Rom Harré (1970) emphasizes this point and said that we do not seek explanations unless there is a change – "*we are not required to explain the fact that something remains the same; only if there is a change is an explanation called for*" (p. 248). Change is therefore an important subject of study in science and in philosophy.

Change in science is studied in terms of change in the state of an object. In chemistry, a chemical equation represents reactants as the prior-state on the left hand side and products as the post-state on the right hand side of an equation. Similar method is introduced by Feynman to represent state transitions in quantum electrodynamics (QED). From the above instances, it is indicative that processes are depicted as state-change model of representation. In biological systems, processes get richer with respect to time, sequence, concurrence, cyclicicity or reversibility. Describing processes in the linear form of text is usually supplemented by diagrams. However, even diagrams also miss out the dynamic aspect of processes. A more prevalent form of graphic representation, such as concept maps packaged with comprehensive, consistent conventions can be effective in representing processes. The objective of this communication is to propose a method for representing change using concept maps by bringing in the existing wisdom.

Our research is informed by the tradition of representing processes in knowledge representation (Dori, 2002, Sowa, 2003) and philosophy (Davidson, 1980, von Wright, 1963). von Wright (1963) proposed a schematic representation of sentences that describe events as – *pTq*, where *p* is initial state of affairs, *q* is end state of affairs, and *T* is the transformation. The states of affairs were considered to be *'features'* of the worlds. The features in von Wright's model is similar to attributes in the knowledge representation model. In Sowa's model of process representation (2003), processes are described as *"evolving sequence of states and events"* occurring in time and are classified into discrete and continuous. According to Sowa, events as opposed to processes, are those changes that occur in discrete steps interspersed with inactive states. He draws a conceptual graph (CG) of the example *'Brutus stabbed Ceasar'* (p. 208) by making the properties of the object more explicit during the process of *stabbing.* Using the CG the process is depicted as *'Brutus stabbed Caesar violently with a shiny knife'* where the '*agent', 'instrument', 'manner', 'attribute', 'time'* etc. are all marked explicitly in the map. Such graphs were used in biology for eliciting students' knowledge structure (Gordon, 1996). In the study, the CG depicts nodes in the form of *concept name, state, event, style, goal, action,* with relations as *'is-a', 'implies', 'property',* and *'consequence'.*

In another proposal for representing processes, Dori (2002) proposes the *Object Process Methodology* (OPM) wherein the process is depicted as change in the state of an object. The three entities in OPM – *objects, processes, states* are building blocks, wherein objects exist, process transforms objects, and states are used to describe the objects. Following the OPM, the process of *melting* is depicted as change in the state of water from ice to liquid whereas in the process of *freezing* the change is depicted as change in the state of water from liquid to ice. In science education, some researchers consider static relations as describing, defining, and organizing knowledge, whereas dynamic relations as those that *"establish implication, functional interdependence and covariation among concepts"* (Derbentseva, Safayeni & Canas, 2006). While Miller and Canas (2008), consider propositions involving physical movement, action, change of state, causal relationship to be of dynamic form.

Concept mapping methodology has been a most influential and widely used tool to represent knowledge that depicts knowledge using concepts and linking words (Novak & Gowin, 1984). It is widely used in research for eliciting, depicting knowledge structure, as a diagnostic tool for students' understanding, misconceptions, in tracing conceptual change, being considered to be facilitating in meaningful learning (Mintzes, Wandersee & Novak, 1997, 1998). However, it has been explicated by Canas and Novak (2006), that although concept mapping tool is used almost worldwide, it is not being used up to its full potential. It has been mostly used for depicting descriptions and so far has not been used in probing for explanation based conceptions, depicting change or thinking about dynamic systems in which objects change over time (Canas & Novak, 2006). One of the reasons being projected was that the focus questions are more description based rather than explanation based. It is also reported that the concept maps have a strong advantage of representing static relations between concepts, but the methodology lacks the potential for representing change or dynamic relations (Derbentseva, Safayeni and Canas, 2004). This certainly calls for re-thinking about the method in order to utilize the concept mapping methodology to its full potential.

As far as the the structure of concept maps is concerned, it has been argued that the structure itself could be one of the reasons that the maps depict more of fact based knowledge rather than explanation based knowledge. It was suggested that concept maps with cyclic structure, which allows concepts to be linked in loops with one input and one output, would be more suited to construct explanatory maps and lead to thinking about dynamic systems, whereas concept maps with hierarchical structure would be creating more of fact based knowledge (Derbentseva, Safayeni and Canas, 2004). One of the hypotheses is that if the concept term is expressed with an attribution such as "number of cars", "color of cars" instead of just "cars" then it can as well lead to increase in thinking about propositions that express dynamic structure (Derbentseva, Safayeni & Canas, 2006). Further, they reported about two strategies wherein they encouraged learners to construct dynamic relations by changing the way a focus question is put forth, as in *"number of cars" instead of "cars"; "how do plants grow?"* instead of *"what are plants"*. These researchers suggested that this strategy triggered learners to think dynamically and construct maps with more quantifiers like quality, quantity, (Derbentseva, Safayeni & Canas, 2006) as in "*quality of soil", "quantity of soil"* instead of just *"soil"*. Later it was substantiated by findings from a study conducted by Miller and Canas (2008), suggesting that posing dynamic focus questions leads to depicting dynamic propositions. The open dynamic focus questions were of kind *"why do birds migrate?", "how do airplanes fly?"* i.e. posing more of *how* questions than *what* questions.

In our review of instances where concept mapping is used in science education, we find that both fact based (static) or inquiry based (causes, change, process, dynamic) expressions are depicted more like a description. In a sentence representing a fact, the proposition expresses a state of affairs for e.g. "*a bottle is on the table"*; "*cell consists of mitochondria"*. Whereas in sentences representing dynamic systems, the propositions expresses a process or set of events, or sequence that involves *change* over time e.g. "*chromatin undergoes condensation"*. The proposition, *"chromatin undergoes condensation"* is object-centric since *'condensation'* is not the focus of attention. However, how this change actually happens to chromatin: what is the prior-state and the post-state of chromatin is also amenable for concept mapping. Even in currently growing field of Biomedical Ontology some authors continue to use object-centric Aristotelian property names such as function, disposition, role, tendency etc. (Arp & Smith, 2008). Considering these known issues, we propose a framework for mapping changes holding to a process-centric view.

Concept maps for Mapping *Change*

Learning from the existing experience of representing processes, influenced from the representation of events, processes, states discussed in science, philosophy and knowledge representation, we propose the following vocabulary and the method for process representation using concept maps. We discuss the method with illustrating examples of mitotic cell division (prophase stage) and few other life processes.

- ***Structure term:*** An object or a system that is undergoing change, for example, *chromatin, cell,* etc.
- ***Process term:*** A term that depicts any change of an object, for example, *boiling, fragmentation, condensation, raining, respiration, pumping of blood, assimilation, growth*, etc.
- ***State of an object:*** We consider the state of an object as the properties of an object at a given time. The properties include the *attributes* and the *relations* of the given object. For instance, during prophase stage of mitosis, the process of *chromatin condensation* can be shown as change in attributes of the object in this case, chromatin. The state of chromatin changes from *long, thin* and it becomes *short,*

dense. A state of an object can also be depicted as relations at a given time, such as *'has location', 'covered by', 'attached to*', etc. During metaphase stage, the alignment of chromosome is merely a change in the location and is depicted as '*chromosome has location towards the pole of the cell*' and towards the end of the metaphase state, the '*chromosome has location towards the center of the cell*'.

- ***Prior-state and post-state:*** As the term depicts, prior-state is the description of the object before undergoing a process, and post-state is the description of the object after undergoing a process. As stated in the above example, the prior-state of chromatin is that it is *long, thin* and the post-state of chromatin is that it is *dense, short.* Similarly the prior-state of location of chromosome is *towards pole* and in post-state it is at the *center of the cell.*
- ***Linking phrases for linking states and process*:** The recommended linking phrases to link two states can be – *becomes, changes to (transforms into, converts into), moves to,* whereas the linking phrases suggested for linking two or more processes can be – *has sub-process, occurs simultaneously, followed by, causes/results in, etc.*

A process term is linked with either a structure term or a process term. If a structure term is linked to a process term, we use the linking phrase – *has role in.* If a process term is linked to a process term we use an appropriate linking phrase e.g. – *has sub-process.* If several processes occurs at the same time then we could use – *occurs simultaneously.* When the sequential or cyclical processes are involved, then we use --- *followed by*. Another prominent form of linking phrase – *causes (has effect/results in)* is used to connect the causal relations in the process. As in most of the processes the change that occurs in the form of state-transformations or state-changes, we depict these with the linking phrase – *becomes*, and wherever applicable if the process undergoes a change in location of the object, it is depicted with the linking phrase – *changes to.*

Given this enriched vocabulary of linking phrases, we can represent the dynamic relations i.e. processes depicting – *sequence, movement, transformation, cause-effect,* etc. Figure 1 shows a process-centric framework for mapping processes applying certain heuristics. In the next section, the proposed framework is illustrated with examples of processes from biology.

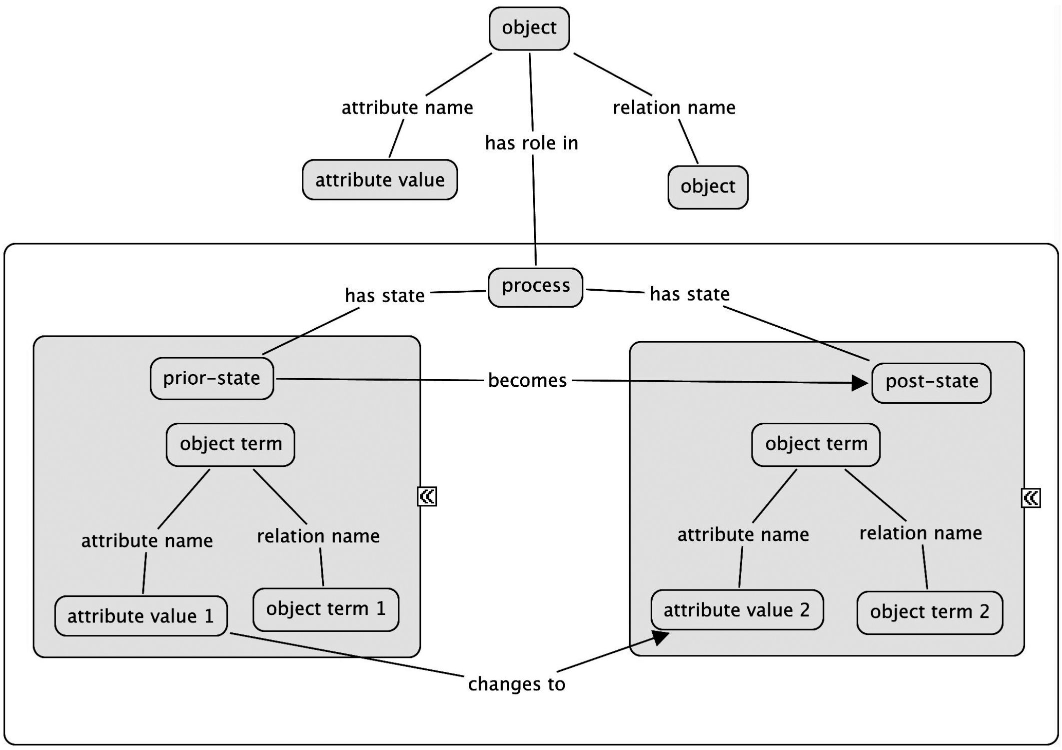

Figure 1. A template for process representation.

Illustrations

We illustrate the suggested mapping of processes taking examples from biology. We take a passage explaining the prophase stage from DeRobertis & DeRobertis (1987, p. 420). We present a regular concept map of this passage and then map the same passage using the proposed process representation framework to make the proposal explicit.

The beginning of prophase is indicated by the appearance of the chromosomes as thin threads insi*de the nucleus. In fact, the word "mitosis" (Gr., mitos, t*hread) is an expression of this phenomenon, which becomes more evident as the chromosomes start to condense. The condensation occurs by a process of folding of the chromatin fibers. At the same time, the cell becomes spheroid, more refractile, and viscous.

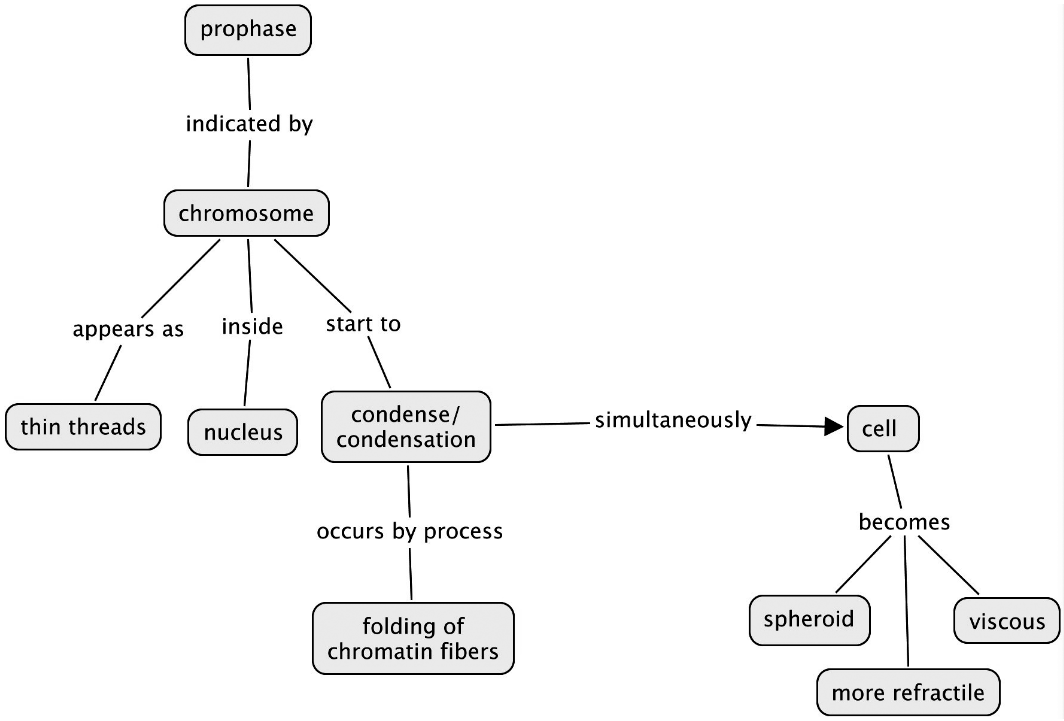

Figure 2. A process depicted using regular concept mapping method.

In the map shown in figure 2, the processes mentioned are *condensation, folding of chromatin fibers, changes in cell*. As we can see that these processes are just mentioned as process terms, and there is no explanation about what actually happens to chromatin during *chromatin condensation, folding of chromatin fibers*. Similarly, if there are certain changes in the cell, then one cannot know what was the earlier state of the cell. If a process alters an object, then it certainly requires that the change needs to be represented.

Our proposed framework suggests using the potential of *"nested nodes"* feature of the *CmapTools* (http://cmap.ihmc.us). Figure 3 shows the same passage depicted using the state change approach. The explanation of processes --- *chromosome condensation* (including *chromatin folding, shortening of chromatid*), *changes in cell* are shown. The process *chromatin condensation* has two sub-processes, one is *chromatin folding* and the other is *shortening of chromatid.* These two sub-processes provides explanation that the prior state of chromatin is that it is *less folded* and *longer in length* and it becomes *more folded* and *shorter*. When these change in state occurs in the chromatin only then we can say that *chromatin condensation* has occurred. Simultaneously with this process, the cell also undergoes changes in terms of becoming *spheroid, more refractile, more viscous*. When we compare both figures 2 and 3, we can see that the later adds more details in terms of providing explanations of "*how changes occurs*", and depicts the process in terms of change in the state of object. Moreover, while mapping the process using the process-centric framework, the implicit knowledge becomes more explicit, thereby bringing in more clarity.

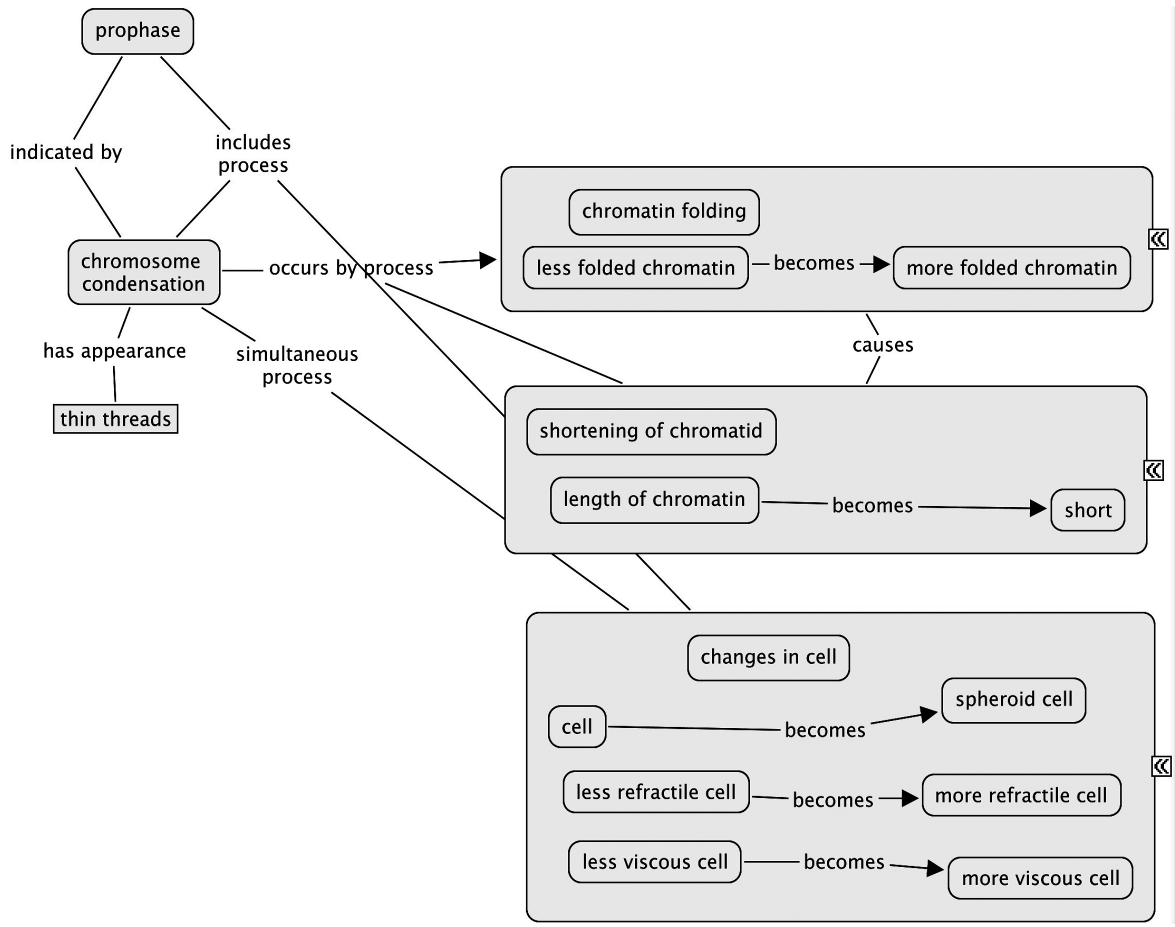

Figure 3. Process representation from an excerpt of the text on prophase. The rectangles holding submap are created using *"nested nodes"* feature of *CmapTools*.

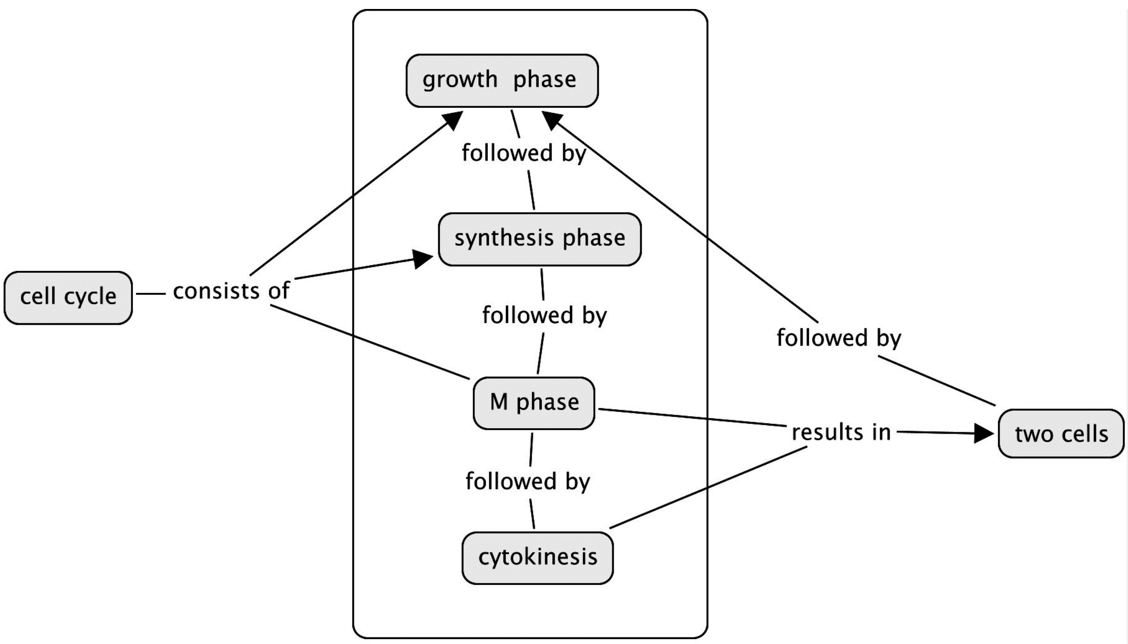

Figure 4. Map depicting sequence and cyclic process.

Applying the above illustrated method, we can now represent various other forms of processes --- *process-subprocess, transformation, sequence, cause-effect* and provide with some examples of life processes.

Sequence

Often we need to represent a sequence of events for depicting cycles, etc. We propose the use of linking phrase -- *followed by* – to depict processes involving sequences as shown in figure 4. In this examples, the various phases of *cell cycle* are depicted.

Cause-effect

As is well known causation has been one of the central idea in science. For processes related to cause and effect, we propose the linking phrase – *cause of / results in.* Another example from basic physiology book from a school is represented using the proposed framework in figure 5.

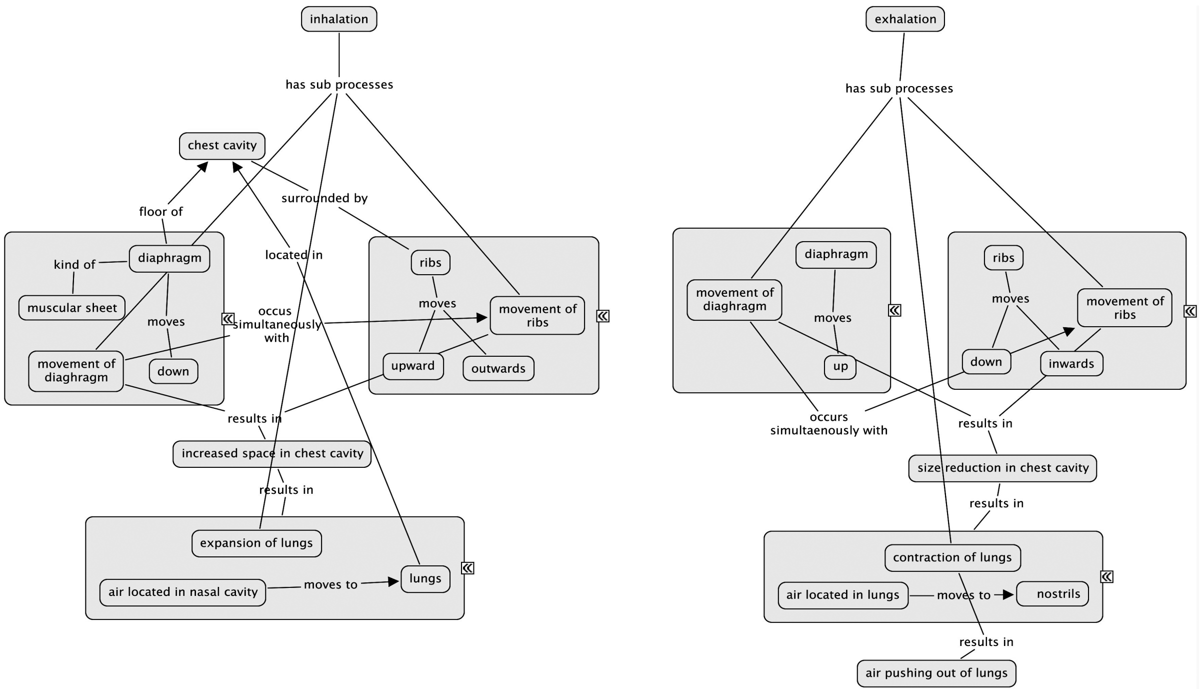

Figure 5. Process depicting cause-effect in inhalation and exhalation.

Discussion and Implications

Though the representation principles used are not novel, the steps suggested are important in the context of science education. As mentioned in the introduction, the science students are required to appreciate the detailed studies of changes. If the representation methods used explicitly seeks their attention to the properties that change over time, it leads to an enculturation of scientific style of thinking. Although, representing of states, processes and events occurring in time is considered to be important strand in knowledge representation (KR), more specifically in philosophy and linguistics (Galton, 2009), this is not explicitly addressed in science education. Within the concept mapping literature, e.g., Kharatmal and Nagarjuna (2011) have provided a list of linking phrases that can be used to represent cell biology domain. However, those linking phrases are mostly used for representing object-centric descriptions. We envision that with the suggested additional linking phrases for process mapping, concept mapping can become a richer tool for science education to bring in clarity and rigor as suggested by Kharatmal & Nagarjuna (2006, 2008). Though we have illustrated the proposal by taking examples from biological phenomenon, other processes like chemical change, ecological change, biochemical pathways, can also be represented. The assumption that concept mapping helps in making meaning explicit is well known (Mintzes, Wandersee and Novak, 1997). Re-representing text in the form of concept maps is an efficient method of making implicit knowledge more explicit. This approach to education is in line with the *Representational Redescription* theory of learning proposed by Karmiloff-Smith (1995).

Another strong point of the suggested approach to process representation is to prepare learners towards quantitative thinking. Since changes often involve a change in measurable dimensions, such as change in *number, position, dimensions, density, temperature, volume* etc., the process nominalization required for quantitative reasoning becomes apparent in this re-representation (Halliday, 2006). Halliday (2006) describes that the hallmark of scientific language is to nominalize processes so as to make them the focus of study. Therefore, we think this style of concept mapping for mapping processes can be encouraged in science education at secondary, undergraduate level. The change in knowledge that occurs while learning (ontogeny) and the conceptual changes (Thagard, 1992) in the evolution of scientific ideas (phylogeny) can also be represented using the same method.

It is to be noted that the process-centric framework applies certain heuristics. The process-centric strategy is just a thought regulating strategy representing process or change. It offers a way of having a check-list and serves as a template (non-exhaustive) when modulating thinking about processes. As the process-centric strategy is build over the prevailing concept mapping method, we think that learners would easily be able to understand the strategy and build their representation on the existing method. It is required that empirical studies should be conducted to study the efficacy and validity of the proposal. Of course the method as such can be done with paper and pencil as well. Considering that the CmapTools already has the support for nesting submaps, the proposal can be tried out in different contexts where processes are the focus of study.

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Using Observations from Classroom Practice to Mediate Teaching-Learning

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Observations have usually been employed to evaluate teachers' practices or to make copious records of students' interactions and behavioural patterns. However, observations also serve a formative function by providing insights about the nature of student engagement, offering opportunities for critical introspection and reflection. The formative function is significant in interventions, such as the one reported, which seek to understand the nature of impact in a learning engagement. A project on Design and Technology (D&T) education, novel to the Indian context, involved development and trials of units among urban and rural Indian middle school students. This paper discusses insights from classroom observations of trials of the D&T units that unleashed the nature of student engagement, informed the pedagogical intervention and contributed to the development of units. Further, insights from observations, form the bedrock for an informed approach towards designing D&T units and making refined judgements about learning strategies and outcomes.

Introduction

The history of human development is replete with instances of learning that are outcomes of designing and making, reconstituting the environment to meet human needs (Burke 1978). Unfortunately, parallel opportunities do not sufficiently occur in learning experiences of a child, especially so in the case of India. Though the recent National Curriculum Framework 2005 emphasizes the need for integrating design and make activities in curricula (NCERT 2005), little has been achieved so far. Salience of such an engagement is emphasized in Design and Technology (D&T) education, introduced as a school subject in several countries across the globe. The need for identifying what could comprise a suitable exposure for the Indian context led to a research and development project. The study presented in this paper is a part of this larger effort. Often, efforts towards analyzing novel interventions are judged either by measures of outcomes or by generalised claims justifying why something worked well. Contrary to this trend, this project focused on several specific aspects of understanding, such as the dynamics mediated by communication in different phases of D&T engagement, studying cognitive aspects in students' design productions, etc. This paper presents insights from classroom observations that mediated teaching-learning.

Observations, as an analytical tool, have usually been employed to evaluate teachers' practices (Jeffries and Maeder 2011), make copious records of students' interactions and behavioural patterns (Ing and Webb 2012) or to provide performance feedback for teachers (Colvin, Flannery, Sugai, and Monegan 2009). However, observations also serve a *formative* function by providing insights about the nature of students' engagement, offering opportunities for critical reflection. The formative function of observations occupies significance in interventions, such as the one reported in this study, which seek to understand the nature of impact in a learning engagement. In order to achieve this function, the criteria for judging interpretations of observations suggested by McCutcheon (1981) are quite useful. These include sufficiency of evidence supporting the interpretation, basing the line of reasoning on defensible assumptions and be reasoned, making significance, and accord with what else is known about phenomenon. Thus, on one hand, observations provide evidences of learning and on the other, give valuable insights for refining teaching-learning.

Objectives of the study

The study reported is a part of a larger project involving research and development towards examining the benefits of integrating Design and Technology (D&T) education in the Indian school curricula. This study aims to address the following objectives:

- To capture the processes of students' engagement without interfering with the dynamics of class discourse
- To develop an interpretive framework, based on insights about the nature of students' engagement in different activities within the D&T units

- To garner evidence-based insights so as to reflect and think about learning experiences and plan the interactions with students in subsequent trials of the D&T units

Methodology

This paper aims to bring to surface insights and observations from the trials of a research and development project on D&T education. The three D&T units involved designing and making: (a) a bag to carry some books to a friend's place, (b) a windmill model that could lift certain given weights, and (c) a puppet and collaborating towards staging a puppet-show. The development and trials followed an iterative model of progression, where feedback from the earlier trials provided inputs for later D&T units and the later trials. The rationale, considerations that steered the selection of these units, and detail of the different phases of engagement within each D&T unit are discussed elsewhere (Khunyakari 2008). This paper reports salient findings from classroom observations across the three socio-cultural settings in the three D&T units. Each D&T unit was carried out in every setting over 15 hours spread across 5 days. Students worked in groups of 3 to 4 individuals. The language of instruction was the same as the medium of instruction in each of the schools.

Sample

Convenience sampling was used to draw sample that consisted of middle school students, studying in class 6 (age 11 to 14 years) from three distinct socio-cultural settings: an urban Marathi medium school, an urban English medium school, and a rural (tribal) Marathi medium school. The tribal school is a government-run residential school or *Ashramshaala*.

Data sources

The data comes from the records maintained in the form of researchers' and observers' notes, logs of daily events, and the audio-visual records of classroom dynamics. The camera panned across the class in any given session and therefore could capture snapshot events of classroom dynamics. In such a recording, it is quite possible that the observers and camera may have missed some portions of interesting classroom discourse. Observers and researchers annotated their observations by noting their immediate impressions of class activities, their reflections at the end of each day of the trials, along with their comments and suggestions. Thus, the notes maintained were interpretive, context-bound and subjective.

Framework for analysis

The analytical framework developed is a qualitative, interpretative one. It draws largely from the empirical findings and analytical categories which reflect considerations that went into developing the D&T units. The framework so developed, summarised in Table 1, has categories of observations with a brief description of the variety of features observed and an example that substantiates findings within each category.

Category	Description	An example
Students' perceptions	Whether ideas shaped by perception of material properties, purpose or aesthetics; stereotypes of locales and people	Stereotypes of physical looks, region and religion influenced character sketch
Content knowledge and skills	Evidences of students' prior knowledge and skills; discussion of structure-function relations; language use and meaning making; problems and discussions on estimation and measurement	Guesses for an English name for a windmill
Teaching-learning events and classroom interactions	Response to specific teaching-learning events; classroom interactions: group dynamics, conflicts and resolution, students' engagement in tasks, non-verbal communication	Human body joints and movements it affords
Resource use	Materials and tools that students ask for, explored and used when made available	Realising card paper as appropriate material for making a bag
Cognitive aspects	Reasoning; justification; evidence of visualisation; evidences of qualitative thinking	Graphical symbols to discuss assemblies

Category	Description	An example
Students' discussion of evaluation	Students' comments on procedures, design productions and each others' products	Expressing the desire to make changes in design

Table 1. Framework for analysing classroom observations

Analysis and insights

Analysis of classroom observations elicited dynamics within classroom and provided insights that informed the later trials in the iterative process of development-cum-trials. The interest in analysis is on *formative aspects* of observations rather than analysing classroom discourse with respect to the settings and units. Insights reveal about what students' brought to the classroom as well as how the classroom discourse shaped their thinking and engagement. An effort is made to summarize the learning incorporated in subsequent trials.

Students' perceptions of tasks, physical (material) and social world

Students' perceptions influenced their evolving design ideas. These included the *physical world* (notions of artefacts, materials and resources, material properties), perceptions of *tasks* (perceived reasons for costing, knowledge of sewing) and the *social world* (stereotypes of gender, attributed expressions and featuring of puppets).

(a) Perceptions of materials and their properties: The interaction between researcher and students from a rural Marathi setting, drawn from researchers' logs, brings out the negotiation about the non-suitability of plastics as a material for designing their bag. Ill-effects of use of plastics had strong explanations, which became evident as researcher posed questions.

[...] = Researcher's translation and comments, (…) = Silent feature recorded

Researcher: People say that we should avoid using plastics, why do they say that?

Students: (after sometime) They create dirt, when it rains it goes with water and blocks the drains

Researcher: What happens then?

Students: It causes foul smell and gives rise to *keedas* [worms] … …

[On plastic being eaten by a cow along with the grass...]

Girl student: *Aatadi la chitkel* [It will stick to the intestine].

Researcher: What will happen then?

Girl student: *Aatadi kharab hoeel* [The intestine will get spoiled]

Researcher: What else can happen?

Student: Cow will die.

Researcher: Like this, many animals die. The plastic gets stuck in their throat. Now if we have to carry all these things [pointing to the books], we will not carry plastic bags. Then what is the alternative?

Students: *Pishvi* [cloth bag] [It is to be noted that *pishvi* in colloquial usage connotes a cloth bag. An adjective is usually used to refer to different kinds of bags. For e.g. *plastic-chi pishvi* is used for a plastic bag]

Such discussions help situate activities in real-life contexts, enhance learning, and foster children's thinking about human and environmental consequences of their design (Hill 1998).

(b) Perceptions of the tasks: While discussing materials, students were asked to estimate quantities and cost. They considered cost of bulk materials and tools but did not account for reduced cost per use of a reusable item, costs of time, labour and marketing. When asked about the reasons for making cost estimations, students exclusively cited reasons associated with monetary gains. Following extract of students' (S1, S2, S3) reasoning from urban Marathi setting is a case in point.

S1: To find out whether the cost [of a product] is high or low.

S2: Since we are all making the same thing, then why we spend more money on that. Because if that thing won't work properly then whatever money we had invested in that will be wasted.

S3: To find out how much we can earn from that.

(c) Perceptions about the social world: Stereotypes of gender, name, dress codes, region and religion seemed to govern students' choices. A group of urban English students resisted to making a female puppet character and researchers had to intervene to convince the worth of taking up the task. Students made inferences about dress codes based on a region (e.g. Widow in London should be wearing white skirt and not a saree) or a person's religion from name (e.g. Dr. A.P.J. Abdul Kalam is a Muslim and a Pakistani). Groups in urban Marathi setting visualised tribal characters with stripes painted on their bodies and producing weird sounds. Students latched onto some ideas early on in conceptualising their designs and retained them throughout. Like professional designers, students' designs were influenced by self-imposed constraints or 'primary generators' (Darke 1984) in their design thinking.

Insights fed into pedagogic practices. For instance, knowing that – (a) class conversations can develop students' sensitivity to consequences of materials used, (b) motivating students to reflect on need for tasks creates metacognitive awareness, and (c) negotiations and authentic contexts for challenging stereotypes can be generated – led to realigning context setting and investigation as an important phase in our pedagogy. All such insights enabled refine the pedagogic discourse and helped researchers appreciate the value of addressing these issues.

Students' (prior) knowledge and skills

As opposed to our conventional classrooms, which are teacher directed, D&T units provide opportunities for students to experiment and engage not just with materials and resources but also language and meaning making. One such evidence is discussed below.

Researcher: What would you call this (pointing to a picture) in English?

Student 1: *Dalnyache kaam karte...* [It does grinding work...] (thinks for a while and replies). *Dalan* [Grind] is *pissing* [meant grinding] in English and it is a *yantra* [machine], so it should be called a *Pissing Machine* [Grinding Machine]. [The Marathi medium students translated *pisne* (to grind) a verb in Marathi language to *pissing* comparable to grinding in English]

Researcher: These objects [referring to the visuals of windmill] run with the help of...

Students: Wind (kept guessing)

Researcher: Wind in Marathi is …

Student 1: *Hava*

Researcher: What else is it called in Marathi?

Student 2: *Vara*

Researcher: What else?

Student 3: *Pawan*

Researcher: And what work does it do?

Student 3: It grinds.

Student 4: What is a *chakki* called in English?

Researcher: It's called a mill.

Student 4: *Pawan-chakki*, Windmill!

Researcher: So the *Pawan-chakki* is called a Windmill, a mill run by the wind.

The transcript demonstrates students' efforts in deriving the correct label by exploring the internalised functional properties of windmill and extending their linguistic competence in vernacular language. Another example, is of the interest generated in learning from their peers a new word, "Ventriloquist". Discussions thus afforded opportunities for use of specific words and widening the general vocabulary of class through peer learning.

Structure-Function relations: The relation between structure and function is indispensable in understanding and thinking about artefacts. Evidences of students' engagement with this relation could be noted while they were conceptualising and discussing ideas, testing and evaluating their products. Another vivid example is of the groups designing dwarfs representing three months in a story-line, who consciously negotiated their ideas across groups to build uniqueness and yet retain the understanding that all puppet characters represented months and therefore needed to be similar.

Estimation and measurement: Students could enumerate the material kinds but had difficulties in estimating quantities. For example, they could not estimate the amount of paper or cloth required for making their bags. In the other units too, they often did not take into account the margins of cloth needed for folding and sewing. The problem was brought to their notice. While some of them modified their design appropriately, others resisted change and went ahead in their making. They found it difficult to insert their hands in the glove and manoeuvre their puppets. They acknowledged this fact in their evaluation and communication of the finished product. In all settings, students in the unit on bag-making, faced problems using a scale to measure and were uncomfortable with the use of units (cm, inches). However, they did know factual information about longer lengths as 100cm was equal to 1 meter. Practice of measuring a range of artefacts was integrated with the session on technical drawing.

Specific teaching-learning events and classroom interactions

The earlier sections discussed what students brought to class and how it influenced their design thinking. This section elaborates on observations from activities which were planned intervention and how students responded to them. Teaching-learning involved a variety of strategies to facilitate learning of concepts and skills to students in context of a design problem: exposure to related artefacts, negotiating meanings through class discussions, sessions on representing objects, eliciting and encouraging multiple ways of design expression (descriptions, poems, sketches, technical drawings, procedural representation, design communication), tool handling skills, etc.

Exposure to a range of similar artefacts was a strategy used to encourage students to compare and contrast, investigate structure-function connections, and draw their attention to subtleties of design. The exercise eventually matured into an important phase of context setting and investigation in our pedagogical intervention. For example, the puppetry unit included discussion on not just different kinds of puppets and their handling but also activities and discussions on mudras and body expression, human body joints and movements, body proportions and perceived stereotypes. Another teaching-learning insight came from our interpretation and learning from students' graphicacy skills. Students' struggle in representing artefacts on 2D was recognised and a session on perspective drawing was integrated. Though able to represent known objects in perspective, students struggled with representation of their design ideas even after the exposure. Realizing the graphicacy problem, the session was replaced by an exposure to conventions of representing 3D artefacts, labels and annotations. They internalised these conventions and used it profusely later in their design productions.

Classroom interactions: Through the various phases of units, students argued, discussed and negotiated to reach to a consensus. They challenged each others ideas, sought clarifications, exchanged opinions and suggested alternatives. On one occasion, urban English medium students negotiated the problem context itself with researchers for the unit on bag (why should one carry bag everyday, make photocopies, etc.). Another evident change was the creation of an ambience of sharing resources progressively through the units. Design and product communication and a variety of activities involving individual as well as group work were included to achieve collaboration at different levels. All through the D&T unit, students relied on non-verbal modes to communicate their ideas within and across groups (Mehrotra, Khunyakari, Natarajan, and Chunawala 2009).

On resource handling and use

Students used resources in their immediate environment as referents or derived structural analogues using concrete objects around while they negotiated their design ideas. For example, groups used scales (rulers) to represent vane assembly in unit on windmill model, paper sheets to model the folds in their visualised bag. Following these observations of students' spontaneous efforts to using concrete materials to externalise their visuospatial thinking in bag and windmill units, the puppetry unit asked groups to make paper templates before they went ahead with using cloth for making. Students' were observed to make reasoned judgements about the appropriateness of materials, tools and resources. For example, when a peer picked up a cutter and passed it on to his team-mate, the student remarked, "*Yeh to plier nahin, cutter hain".* In addition to the materials asked, students were provided a variety of tools and resources so that they could engage and learn novel skills.

Cognitive issues in learning

Observations coupled with students' design drawings and audio-visuals gave insights into cognitive aspects of D&T units, discussed elsewhere (Khunyakari, Mehrotra, Chunawala and Natarajan 2007). Students spontaneously resorted to sketches and gestures to ideate, think and share. They moved beyond analogies (involving mapping of features of source onto target domain). Students used sketches for *interactive imagery,* where source may be retrieved, transformed, reconstructed and/or reorganised (Goldschmidt 2001). Sketches also served as windows to students' thinking. Use of graphical symbols in thinking about assemblies and functioning of vanes is a case in point.

Often faced with the challenge of communicating ideas of complex structural features, dynamic assemblies to their group members, students relied on a variety of modes including gesturing with hands while sharing ideas, discussing, elaborating and reasoning about their designs. Observations of contexts involving gesturing and negotiating among group members seem to concur with the findings of Goldin-Meadow and Beilock (2010) suggesting the dual role of gestures. One, that they contain detailed perceptual-motor information about actions they represent, which may not be found in speech that accompanies gesture. Second, that action features in gesture not only reflect gesturer's thinking but also provides feedback and alter their thinking. Students used qualitative descriptors rather than quantitative and objective estimates even in places which demanded a numeric description. For example, they used non-relative orientations as “vertical” or “horizontal” in the unit on bag-making, described shapes of components as “cylinder shaped” and referred to relative proportions like “equal parts” or “a hole the size of a nail” instead of indicating dimensions. Such spontaneous resort to qualitative usage has been described by McCormick (2004) as *qualitative thinking*.

Evaluation strategies and reflections

A positive change was evident in students' behaviour as they moved from one unit to the other. One of the most evident transformation was observed in girls from rural setting, who earlier were shy and covered their faces with files making while presentation in the bag-making unit became confident, could face questions and even clarify doubts when raised in the unit on windmill model. They became analytical in their evaluation as evident from shift in criteria from decorational aspects to what could contribute to making the artefact sturdy, long lasting or suggesting improvements. While making, students were able to identify and resolve problems either by fixing the problem or restructuring their designs. For example, a group in urban Marathi setting wanted white strings for a handle but felt that they were quite slim. They braided strings together to make a wide and decorative handle. Even the reflections about what could have made their artefact better seemed to be handled by students with great sensibility and practicality, quite evident during group's product communication.

Conclusions and Discussion

The paper presents salient insights from classroom observations that have formatively contributed to the development of D&T education units. The insights have captured processes of student engagement and their relevance for engaging students meaningfully in design and make units. In the process, the inputs have been incorporated in the subsequent iteration and helped assess impact of transformed activity in the subsequent trials and units. Based on empirical findings, an interpretive, context-bound framework for analysing observations has been developed and meaningfully employed. This could serve as a useful starting point for designing suitable D&T units. The interpretation of observations helped analyse students' thinking and allowed researchers to reflect on not just strategies for providing students with knowledge and skills but also in exploring spaces where their understanding and experience can be integrated in an authentic manner. Such an approach opens up greater avenues for developing a critical pedagogy towards D&T education practice in India.

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Development of a Concept Inventory in Rotational Kinematics: Initial Phases and Some Methodological Concerns

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A concept inventory comprises of carefully drafted set of multiple choice questions aimed at probing and assessing student understanding. The questions and their distractors are constructed systematically. The construction process involves theoretical analyses and iterative empirical investigations. In this paper we discuss these steps in the context of the development of our inventory on rotational kinematics. Methodologies which include think aloud protocol, retrospective probing and semi structured interviews are discussed.

Introduction

A concept inventory (CI) is a carefully crafted set of multiple choice questions on a concept or a topic aimed at probing alternative conceptions, deficient understanding and/ or ill suited reasoning patterns. Well developed inventories are ready to use diagnostic and assessment tools. CI's have played significant role in stimulating educational reforms in physics (Hake, 2011). One of the reasons for it is that they can be administered to thousands of students and evaluated easily. Moreover the evaluations are objective and statistically valid inferences can be drawn from quantitative data (Kumar, 2011) . Hake (2011) has provided a review of the impact inventories have made on physics education and related disciplines. He characterized the pre-inventory period of physics education research (PER) as the 'dark ages of post secondary physics education' owing particularly to the limited outreach of PER. The illustrative examples provided by Hake are mostly from the United States. Singh (2011) provides an informative expository article on concept inventories, with emphasis on the Indian context. He has pointed out that the huge student and teacher population makes India a fertile ground for using concept inventories. Major processes involved in the development, administration and assessment of inventories were briefly described. The present paper is intended as a further elaboration on the topic. We have been working towards the development of a comprehensive concept inventory in rotational kinematics at the introductory level.

Our inventory comprises of three parts, namely,

1. An inventory on rotational kinematics of a particle (Mashood & Singh, 2012c).
2. An inventory on rotational kinematics of a particle in rectilinear motion (Mashood & Singh, 2012b).
3. An inventory on rotational kinematics of a rigid body rotating about a fixed axis .

Figure 1 schematically shows the various steps involved in the initial phases of construction of an inventory.

We will illustrate some of these steps in detail. In the next section we briefly describe the theoretical analyses that led to a preliminary draft of our test. This was followed by interactions with students and teachers aimed at obtaining insights so that appropriate items and distractors could be framed. In the third section we discuss the methodological aspects pertaining to our prior interactions and pilot studies. Section IV comprises of description of samples and examples of observations made. Aspects pertaining to validation of the inventory are not discussed in this paper. Examples of our test items along with details of how they evolved are in the public domain (Mashood & Singh, 2012b, 2012c) .

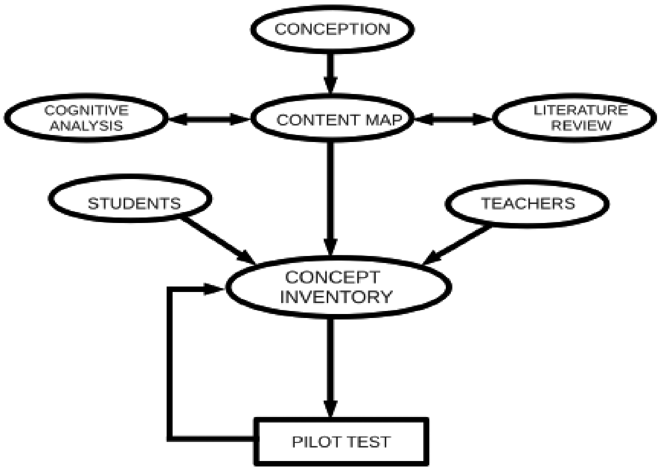

Figure 1. Processes involved in the initial phases of construction of a concept inventory. These steps are followed by validation of the test (not discussed here), after which the inventory is administered to larger samples.

Conception to Content Mapping

We chose rotational motion because it has not received enough attention from the PER community (Rimoldini & Singh, 2005; Mashood & Singh, 2012a). A broad survey instrument on rotation along with rolling motion exists (Rimoldini & Singh, 2005). But even the elementary concepts of rotation like angular velocity $\boldsymbol{\omega}$ prove difficult for students as well as teachers (vectors are denoted by boldfaced symbols throughout the paper). As such focused inventories on the key concepts of the topic need to be developed. Once the concepts are fixed it is followed by content mapping. Here the aspects of the particular concept covered at the concerned level is chalked out. For our inventory we analyzed presentations of rotational motion by popularly used text books. Five introductory level (Giancoli, 2005; Halliday et al., 2001; NCERT, 2006; Reif, 1995; Young & Freedman, 2004;), one undergraduate (Kleppner & Kolenkow, 2007) and an advanced level (Goldstein et al., 2004) text were analyzed. In addition two books in the vernacular language (Hindi) were also consulted (Kumar & Mittal, 1991; Singh, 1988). This was supplemented by a cognitive analysis of $\boldsymbol{\omega}$ and angular acceleration $\boldsymbol{\alpha}$ akin to that done by Reif et al. (1992) for linear acceleration $\boldsymbol{a}$. PER literature relevant to the topic was reviewed (Lopez, 2003; Ortiz et al. 2005; Rimoldini & Singh, 2005; Shaffer & McDermott, 2005; Trowbridge & McDermott, 1980, 1981;). We noted pedagogically significant aspects concerning $\boldsymbol{\omega}$ and $\boldsymbol{\alpha}$ which include

1. The counter intuitive directions of the vectors $\boldsymbol{\omega}$ and $\boldsymbol{\alpha}$, relative to the motion of particle.
2. The derivations of often used equations involving $\boldsymbol{\omega}$ and $\boldsymbol{\alpha}$ and their range of validity.
3. Origin dependence of the angular velocity of a particle.
4. Irrelevance of an origin in the definition of $\boldsymbol{\omega}$ for a rigid body, where the significant aspect is the axis of rotation.
5. Rigid body rotation about a fixed axis dealt at the introductory level is a special case of the general case described by Euler's theorem.

All of these points were incorporated into the inventory by crafting questions involving them (see Mashood & Singh, 2012 b, 2012c for illustrative examples of test items). PER literature review along with our analysis provided us with hints of possible cognitive vulnerabilities. Indiscriminate usage of equations (Reif, 2008), position - velocity confusion (Trowbridge & McDermott, 1980; Hestenes et al., 1992) etc reported in linear kinematics suggested that similar pitfalls may exist in rotational kinematics as well. In addition, we got cued to physically relevant situations like pendulum, elliptical or planetary motion etc where in the questions could be posed. Analysis of the NCERT (2006) text book along with our own experiences helped in figuring out contexts familiar to the Indian scenario such as wall clock, potters wheel, giant wheel etc to pose the questions. Most of our items were consciously framed in such physically relevant and familiar contexts. The initial draft of questions did not have four choices for all items. Some were true - false type and some others open ended as well. It was the interactions with students and teachers that gave the items their final form. The evolution of various items are illustrated in detail in Mashood & Singh (2012b, 2012c). Methodological intricacies involved in those interactions will be the theme of the next section.

Prior Interactions and Pilot Studies: Methodological Intricacies

Interaction with students and teachers is one of the important aspects involved in the process of developing an inventory. A knowledge of the thought processes of novice students helps significantly in constructing good questions/items and distractors. We interacted with around 50 students and 12 practising teachers before administering the test to a larger sample. The students comprised of 21 from the introductory level physics course, 14 doing their bachelors degree, 6 at the post graduate level and 9 pursuing their Ph D's. Some of the interactions were with small groups (2 - 6 students) while others were individual, details of which are described in the next section. The processes were iterative and began with the preliminary set of items/questions described in the previous section. Verbal data was collected, primarily through the following two modes.

1. Prior interactions:
   a) Think aloud protocol: This comprised of candidates answering the questions by thinking aloud. This was often followed by clarifications which progressed into discussions.
   b) Retrospective probing: This involved students solving the questions and we probing at the end of the task. Some students were more comfortable with this mode rather than the think aloud protocol. Such candidates wrote down their thoughts on paper which were collected and analyzed.
2. Pilot tests: This involved candidates taking the test and marking their confidence level to each answers. This was followed by semi structured interviews.

The think aloud data, interviews and discussions were audio recorded and analyzed. The insights obtained were successively incorporated at each stage thereby refining our questions and distractors. Some of the intricacies involved in the above mentioned methodologies are noted here. Think aloud protocol essentially comprises of the subject articulating their thoughts while solving a given problem. The method is particularly useful for providing insights during the early phases of investigation (Young, 2005). This makes it apt to be used in the developmental phase of a test. Cognitively it aims at capturing what is held in the short term memory (Ericsson & Simon, 1993). The primary aim is to elicit the sequence of thoughts as the subject is processing the information. As such the researcher should restrict oneself to minimal intervention so that the stream of thought is not cued or influenced. We, like others, limited ourselves to minimal 'prompts' or 'proddings' such as "keep talking", whenever the subject turned quiet (Rimoldini & Singh, 2005; Young, 2005). It is also important that the problems should be of optimal cognitive load (Young, 2005). A highly demanding problem makes it difficult for the participant to simultaneously attend to solving it and verbalizing. An extremely easy task may be performed with such automaticity that the subject may not be able to describe any sequence of steps. We tried to make our questions optimal in terms of difficulty and ensured that they could be answered without resorting to any lengthy algebraic manipulations. These issues are significant for retrospective probing as well since one runs the risks of memory failure if the task is lengthy. Another important aspect which we took into account was the individual differences in the ability to verbalize. Coming to interviews and partly for discussions, the cognitive analysis of the concepts considerably helped structure our interviews. We tabulated a list of probable methods and arguments participants may invoke. In the following section we discuss the details of the samples and some of the observations made.

Prior Interactions and Pilot Studies: Sample Descriptions and Observations

A. Introductory level students

Interaction with teaching: Four students, who had just learnt their particle mechanics were taught rotational motion by us. This was intended to obtain insights about the difficulties exhibited by novices while trying to comprehend $\boldsymbol{\omega}$ and $\boldsymbol{\alpha}$. While one of the authors taught, the other carefully observed the nuances of the classroom. After teaching, the students were asked to answer our inventory by thinking aloud. Teaching strictly followed a text book (NCERT, 2006), in order to avoid teaching to our items. Our observations borne out of classroom interaction as well as analysis of audio recordings included

1. Difficulty accepting that the direction of $\boldsymbol{\omega}$ was perpendicular to the plane of motion.
2. Ignoring the directional aspect of vectors.
3. Considering circular motion as the prototype of rotational motion.
4. Clumsy reasoning and retrieval, indicating a poor knowledge organization.

Interaction without teaching: This involved three students who had recently learnt rotational motion. Here two opted for retrospective probing. The observations were similar to those mentioned for the above group.

Interaction with high ability students: We interacted with 3 high ability students, who answered the items by thinking aloud. All of them were among the top 30 of physics or chemistry olympiad aspirants. They answered most of the questions easily except for a few. Two were not very comfortable in verbalizing their thoughts and mostly provided answers without qualifiers. Notable errors were made regarding the validity of the equations $\boldsymbol{v} = \boldsymbol{\omega}\times\boldsymbol{r}$ and $\boldsymbol{\tau} = I\boldsymbol{\alpha}$. Here $\boldsymbol{v}, \boldsymbol{r}, \boldsymbol{\tau}$, I denote linear velocity, position vector, torque and moment of inertia respectively.

Pilot test 1: The questions were pilot tested with 7 students. All were asked to mark their confidence level to each answer on a 3 point scale. The performance was unsatisfactory. Interviews affirmed the existence of robust erroneous notions like $\boldsymbol{\omega}$ lies in the plane of motion, rotational motion concepts are relevant only when the trajectory is circular or curvilinear etc.

Pilot test 2: Here 4 high ability students answered the items. The confidence level was high for all items including a few questions which were answered incorrectly. Instances of high confidence level along with wrong answers indicated the existence of pitfalls, which were probed in detail during interviews. For example 3 students confidently maintained that the equation $\boldsymbol{v} = \boldsymbol{\omega}\times\boldsymbol{r}$, holds for all situations.

B. Undergraduate and post graduate students

Interaction: This comprised of 6 undergraduate students and 2 post graduate students. Three preferred retrospective probing. The students were from regional colleges as well as national institutes like Indian Institute of Science Education and Research, Indian Institute of Technology etc. The performance of students from regional colleges were often dismal, at times displaying stark unfamiliarity with elementary concepts like $\boldsymbol{\omega}$ and $\boldsymbol{\alpha}$. Students from national institutes performed satisfactorily, some of them exceptionally well. Notable observations include a student answering questions in variety of ways exhibiting strongly connected network of concepts, some others invoking unnecessary mathematics where a simpler reasoning would have sufficed etc.

Pilot test 3: Eight undergraduate students and 4 post graduate students underwent pilot tests. The interviews with the regional college students ferreted out difficulties which involved poor understanding of the concept of limit and confused reasonings for $\boldsymbol{\omega}$ and $\boldsymbol{\alpha}$, particularly in the context of a simple pendulum.

C. Doctoral students

Interaction: We interacted with four doctoral students in physics. Some of them were out of touch with topics. Still they were ready to reason out and this at times led to digression to advanced aspects of the topic. Discussion of Euler's theorem , Chasle's theorem etc provided us with wider perspectives. Inspired by this, we crafted a few items on the basic definition of $\boldsymbol{\omega}$ of a rigid body.

Pilot test 4: Involved 5 students. Some similarity were observed with the errors of high ability students.

D.Practising teachers

We interacted with 12 teachers. They shared their classroom experiences and aspects of the topics which they found to be difficult. This included the vector nature of the some of the quantities in rotational motion, mathematical operations like cross products, transition from single particle to rigid body etc. The discussion mostly proceeded informally unlike with students. Some experienced teachers suggested problems and questions which could inspire us to create items for our inventory.

Conclusion

We have described some of the initial phases in the construction of our inventory in rotational kinematics, which included content mapping, cognitive analysis, prior interactions and pilot studies. Methodological aspects involved in these steps were also discussed. The inventory which thus evolved got validated by content experts. This marked the final step before the test being formally administered. An inventory is further refined based on inputs from its administration, whenever required. The reliability is established quantitatively using statistical constructs. We intend to discuss validity and reliability in detail elsewhere .

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Students' Measurement Experiences and Responses to Length Comparison, Seriation and Proportioning Tasks

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Measurement is central to the practice of science and should be to science learning as well. Seen from the perspective of science, measurement essentially involves movement from qualitative to quantitative accounts of phenomena. We propose that qualitative experiences of attributes of objects could develop into quantitative measures through some intermediate steps like comparison, seriation and use of a referent. We observed 6 students' measurement experiences and responses to a sequence of questions and tasks on length measurement, starting from experiencing the attribute qualitatively to quantifying it through these steps.

Introduction

Difficulties in the teaching and learning of measurement are well documented in the mathematics education literature (Hiebert, 1984; Bragg & Outhred, 2000; Barrett, Jones, Thornton & Dickson, 2003). This research problematizes measurement as an adult skill to be taught to students while taking account of their difficulties in performing the required tasks. Historically however, measurement arose out of certain needs, admittedly of the adult world, which eventually helped shape the development of science. The underlying motivation, whether arising from commerce, communication or science, was to move from a qualitative understanding of the world to a quantitative one. We suggest that in children too this transition should be seen from a developmental perspective, driven by real-world experiences and actions on the world. The Piagetian concepts of classification, comparison and seriation are used in this paper to frame pre-measurement tasks for students in the primary school. The students' responses are interpreted in terms of epistemic actions.

Measurement in Science

Quantification and measurements are central to discoveries and inventions in science and technology. Measurements are important in testing scientific theories or proposing new ones (Kuhn, 1961). Quantitative techniques bring uniformity and universality to the data and their interpretations, reduce distances in communication and thus, contribute objectivity to the practice of science (Porter, 1995).

Scientific theories and explanations have not always been quantitative. Quantification of time, space and weight emerged out of practical demands that forced an attention to numerical measurements and calculations (Crombie, 1961). For Aristotle, 'qualitative' and 'quantitative' were distinct categories of phenomena and his explanations were largely based on classification. Although Aristotle predicted some quantitative relationships, the predictions did not aim for measurement and calculation. Grosseteste and Bacon in the 13th century began characterizing the Aristotelian 'nature' mathematically. Medieval Platonists, unlike Aristotle, looked for explanations not in immediate experiences but in theoretical concepts capable of quantification. In the 16th century, Galileo's contributions to measurement through his experiments set a milestone in the history of measurement in science (Crombie, 1961). Kepler, Galileo and later Newton contributed to the dynamics that has influenced, to a great extent, the nature of physical science.

Gerard (1961) describes how historically scientific practices in biology moved towards quantification. Sense experiences give us direct qualitative understanding of the objects around. We tend eventually to classify those sensed objects into categories (analogous with observation and examination of morphology of organisms in biology followed by their taxonomic classification). Classification is followed by quantification of static attributes of objects and then the dynamic ones, through measurement (Gerard, 1961).

Guerlac (1961) documents that early in the field of chemistry, the qualitative properties of substances were used in order to classify them. Measurements became important relatively later in classification of substances and in characterizing relationships, first between substances and elements and then between elements themselves.

Guerlac sees a parallel in the qualitative to quantitative movement in science and science curricula. Students, while learning chemistry, usually learn about qualitative analysis of substances followed by a detailed and more delicate quantitative analysis involving direct as well as indirect measurements of amounts (Guerlac, 1961).

In the history of science and in the work of scientists, these transitions happen both from qualitative to quantitative and vice versa (Gerard, 1961). Kuhn critiques the textbook view of science as a process of matching theoretical predictions with experimental measurements. Rather he finds a dynamic relationship between the two, showing how qualitative research, both empirical and theoretical, precedes fruitful quantification, which in turn helps refine a theory or propose a new one.

From 'qualitative to Quantitative': A Parallel tn Science Learning

In the study of the natural world, quantification is typically introduced only late in the school years. In India, the Homi Bhabha Curriculum for Primary Science (Ramadas, 1998, 2001; Vijapurkar, 2004) is exceptional in considering quantitative thinking as a major aim of the science curriculum and introducing measurement activities within the context of understanding the natural world. After NCF (2005) measurement concepts were given an important place in the Indian school mathematics curriculum. Students at classes 2, 3 and 4 now move from qualitative experiences pertaining to lengths/distances to their quantification where they also encounter various concepts underlying length measurement like visual comparison, seriation, partitioning, unit iteration, association of number with space, etc. Measurement concepts are also introduced in the science curriculum but not yet as an essential aspect of learning and doing science (Pande, 2012, unpublished).

Children's understanding of length measurement and the concepts underlying it has been studied from the perspective of mathematics education. The approach has been to diagnose the difficulties that students have in performing measurement tasks and then to develop remedial instructional sequences. This research has focused on difficulties of the transition from use of non-standard to standard units of measurement and on the gaps between procedural and conceptual understanding (e.g. Hiebert, 1981, 1984; Bragg & Outhred 2000, 2004; Stephan & Clements, 2003). It has not addressed the real-world motivation for measurement, i.e. to quantify one's observations, and to move from qualitative experiences to their quantitative understanding. Further, length measurement is rarely connected with development of the child's understanding of space and number. It is in this regard that a Piagetian perspective is helpful.

Developmentally children begin with qualitative notions of near and far, small and big or tall and short. An infant's understanding of space develops through an interaction between visual and kinesthetic-tactile experiences. These experiences are gained via navigation in the world and actions on it (Piaget & Inhelder, 1956; Newcombe & Learmonth, 2005). During the same period and through roughly similar kinds of interactions but supported by schooling, children are developing the concept of number. Measurement concepts related to length, size and distance require an integration of understanding of space with the concept of number.

From a broadly Piagetian perspective, the route from qualitative comparisons to quantitative measurement has crucial intermediate steps. The first is the progression from comparing just two quantities to comparing several quantities, as carried out in a seriation task like placing a number of sticks in increasing or decreasing order of their lengths. Qualitative seriation, when imagined to extend to a very large number of quantities may approximate small equal increments and hence come closer to quantitative measurement. The other intermediate step towards quantification in measurement is where one repeatedly compares the length of some standard or arbitrary unit with the length of an object. The object to be compared is estimated in terms of multiples of the unit (the referent) leading to a numerical measure, say 3 units, 4 units, etc. Seriation also, if it involves a regular increment of such a fixed unit or referent, leads to quantitative measurement. Piaget (1952) considers classification and seriation to be precursors to the cardinal and ordinal properties of numbers.

Piaget however does not examine closely the gestures and actions that occur in the process of acquiring these concepts through real world experiences. For this, the perspective of epistemic actions is helpful. Kirsh (1995) gives a fine grained description of how we think, plan and execute everyday spatial tasks by identifying spatial arrangements that physically constrain actions. The Piagetian and epistemic action perspectives together help us characterize the progression, via the child's actions, from qualitative experiences of the natural world to the quantification of specific attributes of this world, which is precisely the aim of measurement in science.

Developmental stages proposed by Battista (2007) and learning progressions and learning trajectories described by Clements and Sarama (2009) are based on movement from qualitative to quantitative, although they do not use the seriation concept, nor do they closely look at the child's actions. Battista (2007) proposed two stages of reasoning. Non-measurement reasoning which involves visual-spatial inferences like direct or indirect comparisons, imagined transformations or geometric properties (e.g. identifying 'shorter' and 'taller', smaller & bigger etc.) and measurement reasoning involving iterations and understanding proportions.

Aims Of The Study

We propose that some intermediate steps are needed in moving from qualitative experience of an attribute of an object to quantifying that attribute, which are comparison, seriation and use of a referent. Further we have also considered partitioning of continuous object, iterating unit/referent, proportionality and association of number with space (Piaget et al., 1981; Stephan & Clements, 2003) in framing the tasks. Following are the aims of this study.

To explore:

- Students' familiarity with measurement and contexts of measurement
- Students' strategies in length comparisons: do they spontaneously use any referents?
- Strategy for retrieving longer and shorter things: is seriation used spontaneously?
- Students' performance on seriation tasks, specifically their use of epistemic actions
- Students' estimation, partitioning and proportioning abilities

Sample

Six students were selected of whom 2 girls (G1 & G2) and 2 boys (B1 & B3) had passed class 3, one boy (B2) had passed class 4 and one girl (G3) had passed class 5. The participant students lived in *Dharavi* recognized as one of the largest slums in India. They attended the Dharavi Transit Camp School which runs five different media of instruction in one building. Students G1, G3, B1, B2, B3 studied in the Urdu medium and student B2 English medium. The interviews were conducted during the summer vacation, in a room outside of the school premises.

Data Collection

The students were interviewed individually in two sessions of 10-15 minutes each. Student B2 could not participate in the second interview session due to some logistical reasons.

In the first session students were asked to recite numbers and asked them where they used counting. Students were then asked about their ideas of measurement, the everyday contexts in which they used measurement and whether they thought measurement was important. The second session focused on length measurement, proceeding from length comparisons and seriation with everyday objects (9 questions) to seriating a set of 10 cardboard strips of increasing length from 2cm to 20cm in steps of 2 cm. The seriation tasks using strips (6 questions) progressively increased the number of strips from 2 to 10, adding 1 or 2 strips at a time. Finally, students were given two strips, such that the length of the longer strip was in multiples of the shorter strip and were asked, 'यह पट्टी (e.g. 4cm) इस पट्टी (e.g. 2cm) से कितिनी लम्बी है?' ('How much longer is this strip than the other strip?' (7 questions, varying ratios of lengths of strips).

The entire conversation happened in *Hindi*. Interviews were audio recorded and transcribed. They were supported by written notes.

Findings

Reciting of numbers and contexts of counting

Only student G3, who had passed class 5, could count till 100; even beyond 1000 according to her. Student B2 who had passed class 4 could count up to 50. The other four students could count till about 15 or 20 only. All the students were familiar with counting money, rupee notes and coins. Except B1, all mentioned use of counting runs and players in cricket. B1 and B3 believed that counting is related to tables in mathematics. G2 believed that counting was essential so that people do not cheat us while transacting.

Daily contexts of measurement

Students were familiar with the word 'नापना' ('measurement'). All the six students said that they knew about length, height and weight measurement. However, three of them B1, G1 and B3 confused the measure of height to be their age, reporting their past or present height in terms of numbers like 8, 11, etc. The other three students did not respond to the question. Three of the students said that '*Bournvita*' or '*Complan*' (nutrition and energy drinks) were required to grow in height, while one of them thought that with increasing age these drinks needed to be consumed in larger quantities.

Responding to the question, 'Have you observed anybody doing measurements?' (क्या आपने कभी किसी को कुछ नापते हुए देखा है या खुद कुछ नापा है?), student G3 said that her father was a tailor and she often visited his shop and carried out measurements of costumers' body parts and clothing materials using an inch tape. Other students too had observed length measurement carried out by a tailor. One student mentioned distance between two suburban train stations but could not say how it was measured. All the students knew of measurement of weight and amount (meat, vegetables and grains). Student B2 demonstrated with gestures, the use of different 'बाट' (standard weights used by vendors) to weigh smaller amounts (20g, 50g) and larger amounts (1kg, 2kg). G1 mentioned estimation of amount of iron and other raw material required while building a house in relation to the size of the house.

Students believed that people need to measure things in order to sell or buy them. Some of the students believed that counting and measurements were necessary so that people do not cheat while they communicate.

Performance in Comparison, Seriation, Partitioning and Proportion Tasks

Comparison of lengths

When asked to name 'long' objects, students gave fairly non-specific responses like 'animal', 'building', 'bamboo', 'sky' and elephant. Examples of 'short' objects were somewhat more specific like 'younger sister', 'stool', 'nail', 'lice', 'fan', 'ant' and 'crushed stone'. When asked why they had categorized these objects as 'long' or 'short', most gave no responses or said it was 'just so'. Only G2 responded that the bamboo was longer and the fan was shorter than her. Interestingly, all the four 'long' objects listed by all of the five students were longer than themselves, while the five 'short' objects were shorter than themselves. Thus students appeared to be implicitly/unknowingly using their body dimensions as referent for determining 'long' and 'short'. Although gesture data was not recorded in this study, we note that our arm span, which is used to gesture size, is approximately equal to our height.

When explicitly asked to name things longer or shorter than themselves, all except B3 predominantly mentioned people, family members and friends. Remarkably, when asked to repeat names of the objects that they had mentioned, all of the students retrieved the objects in either increasing or decreasing order of length.

Seriation strategies and actions

All the students except G2 assumed an imaginary baseline while placing and arranging the strips. All seriated at least five strips at a time but as the number of strips gradually increased, the students B1, G1, G2 and G3 found it difficult to compare the strips and seriate them, and confusions started arising. Their new strategy involved picking up a few strips of comparable length, identifying either the longest or the shortest strip from that group, and identifying another strip from the same group to place next to it, thus comparing two strips at a time. This strategy is similar to clustering, an epistemic action described by Kirsh (1995). Student G3 also exhibited an additional step of physically categorizing the strips prior to picking and comparing. B3 successfully seriated all the 10 strips by visual inspection without the intermediate action steps.

Partitioning and proportion strategies and actions

Students were given two strips (length of the longer strip in multiples of the shorter (twice, thrice, 4 times and 10 times) and were asked how much longer the longer strip was than the shorter one. Students B3 and G3 approached this task most systematically, aligning the two strips and iterating the shorter strip along the longer one, thus arriving at the correct number (although student G3 in each task attributed the unit '*inch*' to the shorter strip and responded with the respective number followed by "*inch"*. B3 responded with almost the exact numbers followed by the word 'गुना' ('times'). Figure 1 depicts B3's strategy in this task.

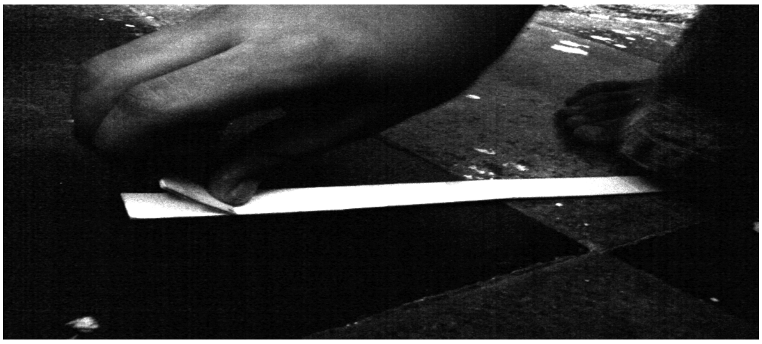

Figure 1. Student B3 iterating the shorter strip along the longer strip

Students B1, G1 and G2 failed to iterate the referent (here the shorter strip) along the longer one. They initially used some repeated gesture along each of the two strips, appearing to use an imaginary arbitrary unit, and counted the number of segments made by these imaginary marks. Figure 2 depicts measurement strategy used by student B1.

Figure 2. Partition and counting strategy of student B1

Figure 3. Student G2 indicating '*this much*' longer using gesture

A little later during the same task both B1 and G2 correctly aligned the two strips and indicated the space on the longer strip that was not covered by the shorter one saying that the longer strip was '*this much*' longer than the shorter strip. G2's strategy in this task can be seen in Figure 3 above.

Figure 4. Student G1 partitioning the longer strip with shorter strip aligned horizontally

Student G1 mentioned that she was imagining the unit marks on a ruler and trying to make similar ones on the strips in order to measure it. Figure 4 shows G1's strategy of measurement. Here, student G1 perhaps exhibited measurement influenced by what Stephen and Clements (2003) call the "mental representation of a ruler".

Summary

Overall performance on the tasks was below what could be expected from students of age 8-12 years. The counting capability of the four class 3 students was only up to 15-20. The daily measurement contexts were limited to tailoring, although one girl had hands-on experience of this task. Spontaneous use of self reference (comparing objects with own body dimensions) was a common strategy in length comparison tasks. Family members and friends were the preferred choices for comparison of heights with self. Length seriation was an implicit strategy used for retrieval and perhaps for remembering objects too. In the seriation tasks as the number of strips to be seriated at a time increased (which in turn increased the cognitive load), a suitable strategy to counter this load was devised by these students: i.e. to break up the task into steps, thus restructuring the task environment. Restructuring often reduces the cost of search to make objects easy to notice, identify, select and place (Kirsh, 1995). Partitioning and counting strategies were spontaneously used by the three younger students while one younger and one older student used iteration to arrive at a proportionality statement.

Concluding Remarks

Mathematics education research has often focused on the transition from using non-standard to standard units. Yet it has been found advantageous to introduce the ruler early and to use both the standard and non-standard units of measurement simultaneously (Nunes, Light & Mason, 1995; Clements, 1999; Boulton-Lewis, Wilss & Mutch, 1996). This paradox is resolved if we look at measurement not as a mathematics education problem but a science education one, i.e. one of developing a progressively more refined understanding of the real world. Consequently, we suggest that the issue to be focused on is not simply one of developing a skill or a competency but rather of enabling a transition from qualitative experiences to their quantitative understanding. In this transition the crucial steps of comparison and seriation are of prime importance to help in teaching and learning of measurement. Action strategies in this regard should be helpful in studying the cognitive processes related to measurement.

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The Achievement Goal Orientation of Disadvantaged Black Physical Sciences Students from South Africa

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The present study attempted to identify the achievement goal orientation of grade 12 Physical Sciences students from disadvantaged communities, and thereafter explain goal orientation by investigating its interaction with teacher, school and parent goal emphasis. The research adopted a mixed methods design involving first a quantitative survey of 300 students from 6 schools using an achievement goal questionnaire developed by Vedder-Weiss and Fortus (2010), followed by interviews with 12 students that served to explicate the trends revealed from the survey. A finding of this study was that disadvantaged Black students have a much stronger performance goal orientation in comparison to a mastery goal orientation. It was also revealed that students perceive the teacher, school and their parent to emphasize such a goal orientation.

Introduction

Poor motivation towards science learning amongst others has been identified as a factor affecting performance in science amongst Black students in South Africa (Mji & Makgato, 2006). This is hardly surprising in view of the deficits in both human and physical resources encountered by Black students in the subject. Research in science education has focused largely on cognition, and there is a need to turn our attention to affective constructs such as student motivation (Schunk, Pintrich & Meece, 2008). Studies have revealed that students' motivation towards science learning declines throughout their years at school (e.g., Galton, 2009). The purpose of this study was to investigate, using the lens of achievement goal orientation the motivation of South African Physical Sciences students from disadvantaged communities in their final year of schooling.

Achievement goal orientation

Motivation to achieve in school can be understood in terms of the different goals students bring to a situation (Ames, 1992). These goals provide students with a sense of direction and a reason to engage in an activity (Pintrich, 2000). A key construct in achievement goal theory is the goal orientation, and this refers to why and how students engage in academic activities (Vedder-Weiss & Fortus, 2010). The theory specifies two main goal orientations. With a mastery goal, the focus of attention is on the intrinsic value of learning (Meece, Herman & McCombs, 2003) with an orientation towards developing new skills, understanding the work, improving one's competence and a sense of mastery based on self-referenced standards (Ames, 1992). Students who adopt mastery goals tend to persist in the face of difficulty, seek challenging tasks, and have high intrinsic motivation (Ames, 1992). The second orientation according to this theory is a performance-approach goal, where the student's main concern is the outward showing of competence (Ames, 1992). Especially important to a performance orientation is public recognition that one has done better than others or performed in a superior manner (Meece, Herman & McCombs, 2003).

The benefit of examining goal orientations is that we become better informed on the reasons why students achieve in academic settings (Anderman, Austin, & Johnson, 2001). This information can provide guidelines on how learning environments need to change so that learning can be optimized (Stipek, 2002).

Influences on achievement goal orientation

Achievement goal theory highlights environmental characteristics that may foster different orientations (Mucherah, 2008). These include teacher-related classroom factors, school culture and parental influence. Epstein (1989) identified six classroom factors that affect motivation: task design, distribution of authority, recognition of students, grouping arrangements, evaluation practices, and time allocation. School-wide characteristics can be referred to as "school culture" (Vedder-Weiss & Fortus, 2010) and it has been suggested that they may play a central role in fostering or de-emphasizing students' mastery goals, beyond the influence of a certain teacher (Kaplan & Maehr, 1997). Barth (2002) defines school culture as a complex pattern of norms, attitudes, beliefs, behaviour, values, ceremonies, traditions and myths which is deeply embedded in each aspect of the school. Studies have indicated that parents influence their children's motivation for learning in science (e.g., Breakwell & Beardsell, 1992). There is evidence to suggest that students who receive much support and encouragement from their parents tend to adopt mastery goals and demonstrate more persistence and effort when faced with difficult and challenging learning tasks (Hokoda & Fincham, 1995).

Against this background, the following research questions are formulated:

1. What is the achievement goal orientation of disadvantaged Black Physical Sciences students?
2. Is there an interaction between student perceptions of teachers', schools' and parents' goals emphasis for science learning and their achievement goal orientation?

Method

This study adopted a 'sequential explanatory mixed methods' design (Creswell, 2002). An achievement goal questionnaire developed by Vedder-Weiss and Fortus (2010) was administered to 300 grade 12 Physical Sciences students from 6 township schools. In South Africa, the term township usually refers to underdeveloped urban living areas that, from the late 19th century until the end of Apartheid, were reserved for non-Whites (Black Africans, Coloureds and Indians). The questionnaire is comprised of items which have been developed to test student perception of the two goal orientations in science achievement already described and constructs relating to teacher, parent and school goal emphasis (refer to supplementary file for constructs and items). The items were statements to which students had to respond on a 5-point Likert scale that ranged from 1 (not true at all) to 5 (very true). The internal reliabilities of contructs to which items were related were evaluated by calculating Cronbach's alpha for each scale. Items that interfered with the reliability were deleted. Eventually, the Cronbach alpha exceeded 0.7 for all constructs.

The questionnaire data was analyzed by computing scores on the above achievement goal constructs (scales). Correlation analysis was used to describe the strength and direction of the relation between the constructs. Interviews were then conducted with 12 students exhibiting an extreme goal orientation. The interview served to probe students on possible factors influencing their goal orientation.

Findings

The findings from the analysis of the questionnaire survey were integrated with the findings from the student interviews into a coherent whole. The interview data explained some of the findings which emerged from the questionnaire analysis. This integration of quantitative and qualitative data supported the production of assertions (Gallagher & Tobin, 1991) on the achievement goal orientation of students. These assertions are presented next.

Table 1 presents descriptive statistics on the analysis of the 300 student questionnaires

	M	SD
Student mastery goal orientation	2.35	1.06
Student performance goal orientation	4.23	0.81
Student perception of teacher mastery goal emphasis	2.80	0.96
Student perception of teacher performance goal emphasis	4.18	1.21
Student perception of school mastery goal emphasis	2.60	1.13
Student perception of school performance goal emphasis	3.98	0.87
Student perception of parent mastery goal emphasis	2.10	0.93
Student perception of parent performance goal emphasis	3.92	1.13

Note: The above scales range from 1 to 5

Table 1. Mean and standard deviation for achievement goal constructs

Assertion 1: *Disadvantaged Black Physical Sciences learners perceive that they have a stronger performance goal orientation than a mastery goal orientation.*

The results depicted in Table 1 indicate students from disadvantaged communities have a stronger performance goal orientation than a mastery goal orientation.

The above result suggests that students are strongly motivated by achieving good marks in assessment tasks and getting recognition for performing better than their peers. For example, in responding to the item "In our science class, it's important not to do worse than other students" that related to performance goals orientation, the means score was 4.4. All 12 students interviewed exhibited a strong performance goal orientation. In the interviews the students were questioned on what motivated them in science learning. The following interview responses underscore the performance goal orientation of students:

> I want to do very well in science to get high marks. I try hard to get this and do all my work every time.
>
> When I study for a test I go over all the work from start to finish. I memorize all the definitions so that I must not lose any marks.
>
> I must get good marks to show my classmates who is good. I want to prove it with the high marks in science.

In contrast, the much lower mean score for the mastery goal orientation shows that student achievement goal is weakly driven by the intrinsic value of learning science, namely the development of conceptual understanding in science, and science process skills. This is further evidenced by student responses to the item "An important reason why I do my science class work is because I like to learn new things" where the mean score was 2.8. Eight of the twelve interviewed student responded "not true" to this statement in the questionnaire. When asked to elaborated upon this response, they indicated that they willingly complied in doing their classwork whenever the teacher informed them that it was for assessment purposes, while on other occasions they did not attach the same importance to the task. They were quite candid in advancing that the objective of learning science by doing the classwork set by the teacher was secondary to their primary goal of getting a high mark for the task. The following responses attest to this observation:

> Sometimes I do enjoy the classwork set by my teacher, but I always hope to get some good mark for this. The mark shows me if I am doing good and learning a lot.
>
> We can always do the work, but we must show something for it. I can do well in learning by having the mark for it.

The influences accounting for these findings on the achievement goal orientation of students were then investigated, and the next assertion relates to this.

Assertion 2: *The performance goal orientation of learners is related to the goals emphasis of teachers, the school and parent as perceived by learners.*

A correlation analysis was performed to examine how student goal orientation was related to teacher goal emphasis, school goal emphasis and parent goal emphasis.

It was evident from this analysis that there is a strong, positive correlation between student performance goal orientation and teacher performance goal emphasis ($r = .66$, $p < 0.05$). This relationship was explored further in the interviews. The students alluded to the emphasis placed by the teacher on getting high marks on assessment tasks and instilling competitiveness amongst learners. This is evident in the following excerpts from the interviews:

> I need to do well because my teacher compares our marks to each other. Those getting the good marks are praised.
>
> I feel so good when I get a higher mark than the others because the teacher is very happy. He even singles us out and lets us do whatever we want for some time.
>
> I get scared to get a bad mark. My teacher gets upset and shouts us insults. I feel like I must always do better than the others.

It is clear from the above responses that these students are motivated to achieve in science by their desire to appease the teacher who attaches great importance to performance in the subject. There is also a suggestion from the last response of the student's performance avoid goals emphasis where the learner adopts a performance goal orientation to avoid being discriminated due to poor performance. The significance of the strong correlation between the performance goal orientation of learners and the perceived performance goal emphasis of teachers is reinforced by the large extent to which teachers are perceived to emphasise a performance goal in their classroom (student perception of teacher performance goal emphasis, $M = 4.18$, $SD = 1.21$) (Table 1). This perception by students appears to be shaped by classroom factors such as evaluation practices, the authority of the teacher and grouping arrangements. All twelve interviewed students indicated that the assessment tasks given were predominantly summative and comprised of tests and examinations. Assessment feedback on academic performance appeared to be judgemental rather than being continuous and formative. When asked to describe any activities that did not count for marks, they could only recall a regional science expo that some learners participated in. Assessment was therefore geared towards a performance goal emphasis.

In exploring a link between the classroom distribution of authority and the goal orientation of students, they were asked to describe a typical science lesson. It was inferred from their responses that the lessons are heavily teacher-directed with students being given only limited opportunities to explore their own ideas through stimulating activities. The following interview responses elaborate upon this:

> We spend most of the lesson listening to our teacher and then take down notes. I thought science was supposed to be fun like in the primary school. Here we just sit and have to write a test. We must listen carefully so we know how to answer the test questions.

> We are always doing a lot of work. This is my second science notebook. Mr Mkhize *(the teacher)* gives a lot of notes from the board. We study it hard to try and pass, but I am struggling. Sometimes we can ask questions, but we have to keep pace at all times.

The classroom seating arrangement supported a teacher controlled environment. Based on the description given by the interviewed students it was clear that they would normally be seated in rows facing the teacher. When questioned on why they believed the teachers seated them in this fashion, they referred to this being the most effective way for them to all listen to the teacher and follow his explanations so that they could do well in tests and examinations. This is clearly evident in the following interview excerpt:

> We face the board most of the time because the teacher is there. He wants us to be always looking front to concentrate on the lesson. We must listen to him so we don't miss out on anything to come out in the test.

> This is best for us all to be looking at him all the time. We cannot turn around to discuss anything unless he tells us.

It is therefore evident the classroom factors support a performance goal orientation where they are motivated by the imperatives of getting a good mark in science.

An analysis of the student perception of the schools' achievement goal emphasis revealed that they strongly believe that the school attaches more importance to a performance goal ($M = 3.98$, $SD = 0.87$) than a mastery goal ($M = 2.6$, $SD = 1.13$) (Table 1).

The strong positive correlation between student performance goal orientation and the schools' performance goal emphasis as perceived by students ($r = 0.63$, $p < 0.05$) reflects an association between these two construct. When learners who displayed a strong performance goal orientation were asked to explain their orientation, they made reference to how the few learners who performed well in tests and examinations received high praise and were given special recognition. This was evidenced in the following responses:

> At this school the top learners are treated like heroes. It is all about getting the highest mark. The awards ceremony is a big thing and the principal sometimes goes over the top and saying we must all do the same.

> We are made to look stupid in front of the achievers. I am good at sport but they don't worry about that now. It is now all about passing your school work

They also spoke of the school principal who closely monitors their progress throughout the year. When asked to explain why they thought the school principal placed such a strong emphasis on them doing well, the students alluded to how the management of the school was under pressure from the provincial department of education for them to do well in science. In the responses below the students refer to their school as being one that has been identified by the department of education for support due to a poor performance in the previous year's national grade 12 examination.

> Mr Jabu *(the principal)* must make sure we can pass. I see officials from the department coming all the time. They are always coming and checking our books. Mr Jabu will lose his job if we fail at the end of this year.

It was also evident that when students underperformed, much pressure was brought to bear upon them by the management of the school. In such cases students were "summoned" to the principal's office and sometimes parents were invited to discuss their child's progress. This is clear from the following response:

> If you are not making it in grade 11 you can be made to leave. Sometimes they even ask you to register as a private student. You can also expect your parent to be called.

Furthermore, the strong negative correlation between student performance goal orientation and student perception of the schools' mastery goal orientation ($r = -.61$, $p < 0.05$) shows that the high levels of student performance goal orientation was associated with lower levels of the schools' mastery goals orientation. This negative correlation is largely explained by the schools emphasis on test and examination performance at the expense of the intrinsic value of science learning characterised by the development of understanding, skills and the enjoyment of science.

The correlation analysis shows a strong positive correlation between student performance goal orientation and students' perception of parent performance emphasis ($r = .61$, $p < 0.05$). This indicates a strong relationship between these two constructs, with high levels of student performance goal orientation associated with high levels of parent performance emphasis. Students also perceive that their parents have placed a much heavier emphasis on performance ($M = 3.92$, $SD = 1.13$) than on mastery goals ($M = 2.1$, $SD = 0.93$) (Table 1). The interviewed students referred to how parents believed that by them getting high marks in science, it would lead to self-advancement by improving the prospects of them getting a good job. This is apparent from the following excerpts:

> My parent sees good marks in subjects like science and maths as creating opportunities for me to further myself. They believe your future is secured through high marks and doing well in the exams. They always remind me on this.
>
> I can say that my dad is really hoping for me to do better than the other children. He always says it is a tough world out there and I must show at school that I am better than the others. He thinks a good symbol in science will give me a bright future.

When asked about whether their parents wanted them to enjoy the learning of science, the students indicated that their parents attached less importance to enjoyment of the subject and more on them getting good marks in the subject. This is underscored by the following interview excerpt:

> I am sure they want me to like and enjoy doing science, but at the end of the day it must be about scoring high marks. Enjoying science doesn't count for them.

The interviewed students also commented on how when they performed poorly at science their parents reprimanded them for this by denying them recreational privileges such as attending soccer matches and going to the movies.

Discussion

A finding of this study was that disadvantaged Black students have a much stronger performance goal orientation in comparison to a mastery goal orientation. This finding is not surprising given the focus on high-stakes summative assessment in the form of tests and examinations in the South African education system. According to Harlen and Deakin Crick (2003) the assessment activities used in the classroom convey important information to students about its value, and hence have an influence on their achievement goals (Ames, 1992). The importance students attach to getting good marks, especially in comparison to peers was also underlined in a systematic review of research on the impact of high-stakes tests on aspects of students' motivation for learning (Harlen & Deakin Crick, 2003).

Research on learning in relation to the goal orientation of students points out that mastery goals in science learning has a positive relation with desired learning characteristics and therefore should be encouraged and fostered by parents, teachers, and schools (Patrick & Yoon, 2004). Against this, the finding of this study does raise concerns regarding the dominant performance goal orientation of students and their weak mastery goal orientation. Despite disadvantaged students being motivated to perform well and achieve high marks in science, the dismal grade 12 results in the national Physical Sciences examination does suggest that a performance goal orientation of learners may not be ideal.

The results of this study show that students perceive their teachers to have a strong performance goal emphasis. This finding correlates well with other studies that have pointed towards the establishment of classroom environment established by the teacher as being a significant determinant of student attitude and goal orientation (Myers & Fouts, 1992; Simpson & Oliver, 1990). The implication of this finding is that there is a greater need for research to identify those aspects of science teaching that make school science engaging for students.

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Exploring Students' Understanding of Species: A Study with Class VIII Students

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The paper reports an exploratory study on middle school level textbook representation of concepts of species and Class VIII students ideas of species. Thirty seven students (mean age: 13) participated in this study. It was found that students hold complex or hybrid views about species. Students' idea of the ability to inter-breed and similar characteristics among individuals of a species category, is similar to the textbook definition. However, their idea about species remain restricted to animals only. It is found that even school textbooks portray diversity of animals more than diversity of plants. Students hold several alternative views and misconceptions about species. The paper attempts to link textbook representation of species and students' understanding of species.

Introduction

In biology, the concept of species "is one of the primary levels of integration" among systematics, genetics, ecology, physiology, study of behaviour, etc. (Mayr, 1957 as in Richards, 2010). Though the study of evolutionary biology relies on an understanding of species (Cracraft, 2000), the studies on students' conception of species have been fewer than needed (Munson, 1994). According to, Leach et al. (1992), children between 5-16 years of age could recognise three different "varieties" of dogs as dog. However, only a few 16 years old students could state the rational they used in grouping all the three varieties of dogs as dog. These 16 year old students mentioned genetics as the basis of their grouping but had no knowledge about "the genetic basis of the species concepts".

The current understanding of species, does not provide definite answers about whether all dog varieties are members of same species (Hey, 2001). The multiplicity of species definition demands careful attention from school level biology educators on how the concept should be taught. Sharp (2009) has developed a teaching module for university students which introduces speciation through several species concepts. However, similar documentation for middle and high school students is lacking.

The concept of species: history of the debate

"Species problem" is a century long debate (Richards, 2010). The history can be traced back from the time of Aristotle. The Aristotelian view defines categories as "characterized by a property or set of properties that are necessary and sufficient for membership in that category". All the characteristic properties together form the essence of a category. From the similar understanding species is a category and each species has an essence of that species. Such understanding of essence stems from "realist view" and provides each category an ontological status (Hey, 2001). In contrast, according to Darwin's theory of evolution, species is something that evolves from another species, changes over time, produces new species and eventually may become extinct and therefore is not fixed over time (Francis, 2007; Richards, 2010). Several centuries in evolutionary biology have enriched our understanding of origin of species but the progress has led to further difficulties in defining the species itself.
Darwin himself held nominalist view about species:

> *...we shall have to treat species in the same manner as those naturalists treat genera, who admit that genera are merely artificial combination made for convenience. This may not be a cheering prospect; but we shall at least be freed from the vain search for the undiscovered and undiscoverable essence of the term species. (Darwin, 2004; pp. 665)*

Probably, Darwin's caution of "*vain search for the undiscovered and undiscoverable*" has dampened the efforts of biologists' attempt to define species. Interestingly, there was a renewed interest in the origin of species in the 1930s and 1940s and again in 1960s to 1990s. However, most of the research is scattered in technical journals (Cracraft, 2000; Coyne and Orr, 2004).

The question is whether species are discrete or continuous; "real", "objective entities" or "purely arbitrary constructs" of human mind. Only if species are "real" entities then can we attempt to define them (Mayr, 1982;

Coyne and Orr, 2004). According to Biological Species Concept “species is a group of interbreeding organisms that is isolated from other such groups” (Mayr, 1996). Naturally, the definition fails to account for the asexually reproducing organisms (Hey, 2001; Richards, 2010).

Conceptualizing species as 'real' biological entity amounts to “species fixity” and is inconsistent with the understanding of Darwinian speciation (Mallet 2001, as in Coyne and Orr, 2004). However, in most cases the process of speciation is so slow that in any experimental time scale, species will be like a discrete species (Coyne and Orr, 2004).

For Levin (1979), species is an abstract construct that gives a sense of diversity in the living world. Researchers use convenient working definitions of species for organism under study in either explicit or implicit ways. There are studies that show correspondence between “folk species” and “Linnaean species” but the findings are insufficient to conclude that “species are real rather than nominal categories” (Hey, 2001).

Significance of species concept in conservation biology

Species is the fundamental unit of biodiversity. There are disparities in species counts and most of the discrepancies arise due to different ways of defining and conceptualizing species by the respective researchers. There are more than 22 species concepts (Mayden, 1997), that too incomplete and none of them “seems adequate” (de Queiroz, 1999). The multiple definition of species has serious implications in conservation biology. Firstly it poses ambiguity in counting the total number of species and impedes implementations of biodiversity conservation legislations specific to species conservation. Another serious problem is in identifying specific disease causing species (Richards, 2010).

Motivation for the study

The recent, Indian National Curriculum Framework (NCERT, 2005) envisioned a shift towards constructivist teaching and learning. The position paper National Focus Group on Teaching Science mentioned six criteria to fulfill in an ideal science education curriculum: a) cognitive validity, b) content validity, c) process validity, d) historical validity, e) environmental validity, and f) ethical validity (NCERT, 2006a). In response to the framework, a new set of textbooks has been developed to address the goals mentioned in the policy document (NCERT, 2006b). Now it is important to know how students understand or interpret the textbook content, which can be used as feedback for regular teaching to avoid misrepresentation of the content. Moreover, it is important to carefully analyse the content and presentation of the content in the backdrop of above mentioned six validity criteria. The textbooks are analysed for the content and cognitive validity only. The study with students have explored the students' understanding of the species concept and their possible connection with textbook as a learning source. It is hoped that the analysis would provide inputs and insights for further improvements of textbooks and classroom discussion.

Study

The course was conducted over eight days in two sessions with students of class VIII titled “Energy and Environment”. In the course students were mainly introduced with energy, sources of energy for human use, environment and ecosystem in particular, photosynthesis, energy and material flow in the environment, increasing energy need and possible environmental consequences. The sessions of the course consisted of multiple modes of interaction and students' productions in terms of completing worksheets, whole class discussion, guided activities etc. (Shome, 2009). In this study we will report only students' ideas of species in response to completing a worksheet on “Environment”.

Participants

Forty students (30 boys, 10 girls) of Class VIII of mean age 13 from three English medium schools voluntarily participated in the course. Thirty seven of the students (28 boys, 9 girls) were present on the day of this study. Announcements of the course for the students of class VIII were sent to each school. Guardian's written consent was taken before accepting participants to the course.

Research Question

The study was guided by three major questions. The first question addressed the content and other two addressed the cognitive aspects.

1. What ideas do textbooks portray about species?

2. What are the students' ideas about species?
3. What is the relation between the ideas expressed by students and those in textbooks?

Framework of the study

According to the constructivist paradigm of learning, students do not passively receive information. They construct their knowledge based on their prior understanding. Students' understanding of living and non-living, animals and plants have been studied in the Indian context. It is found that most students consider only larger animals in animal category and exclude fish, insects and human beings from the category. Moreover, students show a preference towards animals over plants in their discussion of living beings (Chunawala et al., 1996; Shome, 2009). Their concept of species would also be connected to how they conceptualise plants and animals. Textbook is an important source from which students construct knowledge. Therefore, it was important to study whether the textbook presentation of content in some way reinforces the existing misconceptions, or presents some conflicting ideas.

To address this aspect and answer the first question all the NCERT science and social science textbooks from Class I to VIII were analysed. Addressing the second question was important for two reasons. One is to explore students' species concepts before introducing them to ecological concepts. And second was to help address the third research question. In the study students' existing ideas have been viewed as potential instances for initiation of discussion in the classrooms and not as misconceptions. The ideas would have origin in their history of evolution of concepts itself. And some of them would still be valid. Therefore, the existing students' conceptions become a resource for rich classroom discourse. The focus of the third question was to find a correspondence between students' ideas about species and textbook representation of species. Becoming aware of these two dimensions would help teachers to address the concept better in their classroom teaching learning.

Data and findings

Textbook analysis

The soft copies of all the NCERT textbooks on science and social science for Class I to VIII were searched for the word “species”. The chapters containing the word “species” were first identified and sentences include the word species are listed. Next, all the sentences (only from the chapters mention the word species) those mention organisms and their varieties in relation to species are listed. The related sentences or in some cases phrases in the exercise as well as summary of the chapters were also included in the analysis.

All the selected sentences were listed according to the Class, subject and chapter. The sentences were read several times to find some patterns on: concepts of species introduced in the textbooks, and variety of organisms are associated in the context of “species”.

Findings

The word “species” first appeared in Class VI Geography textbook in the context of Biosphere. When it appears in the next higher class in the same subject, it tends to be more about animals in the discussion of species. It is interesting that except in Class VI Geography and Class VIII Civics, all textbooks predominantly gave preferences to animals in connection to species.

It is important to note that Class VIII Science introduces a chapter on “Conservation of plants and animals”. The chapter discusses the causes of deforestation and associated environmental change, threat to biodiversity, idea of endemic, endangered and extinct species and also provides a definition of species.

Except Class VIII, Science, all textbooks have devoted almost same number of sentences to describe the diversity of plants and animals. The textbook devoted 13 sentences to explicitly mention the animal diversity, while plant diversity is mentioned only by two sentences. At the same time, the explicit mention of names of animals in these chapters of Science are three times as high as that of plants. Interestingly similar disparity (close to two times) between these two is also evident in Geography textbook of the same Class and Class VI as well.

Student questionnaires

In the worksheet on “Environment” students were asked to define the term “species”. The question was open ended to get rich responses from the students. The responses were listed in text document and later rephrased in terms of complete sentences without changing the meaning. All the sentences were read several times to develop a coding scheme. The coding scheme was validated by two scorer-raters and sufficient agreement (91%) was reached.

Findings

The preliminary analysis of students' responses suggest two major categories of ideas on species. Primarily students view species as either organism or animals. Only one student's response was not coded due to its ambiguity. Therefore, sample size is considered as 36 for all percentage calculation.

1. Species are organisms: In this category of responses students (19 students, 53%) explicitly mention about organism or mentioned both the plants and animals or it implies to have included both. For example, definitions given by one boy and one girl are given here respectively:

   "There are different types of or varieties of animals, plants and birds. They are called as species."(M/18).

   "Species are a particular group of organisms of the same type" (F/10)

   An example of response, where, organism is implied is given below.

   "Species are living organisms or animals that are living in the earth". (M/22)

2. Species are animals: Seventeen (47%) of the students responses fall in this category.

   "A group of animals which have same characters" (M/16).

Interestingly, the students' responses from both the above category follows one similar structure. Equal number (3) of students from both the categories associated species with members' ability to interbreed and having same character.

"Species are a particular group of organisms of the same type, which are capable of reproducing fertile offspring of their same kind." (F/10)

"The group of animals which posses common characteristics and are capable of interbreeding are called species." (F/2)

Six students from each of the category associated species with either ability to interbreed (3/2) or having same character (3/4).

"Species are those who are capable of interbreeding." (M/17)

"These are the animals which have a characteristics of interbreeding i.e. that they could reproduce within themselves and not with some other species." (F/12)

Nine (25%) students (4 and 5 from category 1 and 2 respectively) characterises species as endemic only.

"Species are animals found in a particular area." (M/13)

Total four students from both the categories classified species in at least one of three species categories mentioned in the textbook viz. endemic, endangered, and extinct.

"Species are living organisms or animals that are living in the earth. There are two types of species one is endangered species and second is endemic species." (M/22)

"There are two types of species: endangered and extinct..." (M/16)

Interestingly two students (1 from each category) associated organisms or animals related to other organism or animal in defining species.

"Species are a kind of animals who are related to a same group etc." (M/10)

"Species is a type of animal or a creature related to a particular animal/creature" (M/20)

Three students from first category mentioned species as varieties of living world. One of the student associated the idea of variety for a common class of animals, e.g. snake.

"There are different types of or varieties of animals, plants and birds. They are called as species." (M/18)

It is interesting to note that a few students conceptualise species as microscopic and harmful, rarely found, having large populations, and useful for human and environment only.

"The species are the animals which we can see with the microbes (microscope). They are harmful to us." (M/22/2)

"Species are some special kind of animals which are found very rarely for example – white elephant, white tiger..." (F/25)

"A species is a living organs (organism) which have a large number of population and have same kind of characters." (M/19)

"Species are those which are capable of human activities. They are important for human and the environment." (F/27)

Discussion

It is clear from the preliminary textbook analysis that portray of diversity of plants and animals are not always balanced. Particularly, the Class VIII, Science and Geography textbooks failed to present animals and plants with equal emphasis. One of the sources of students' misconception about species as "only animals" might have developed from the textbook itself. In textbook students were introduced to the biological concept of species (Mayr, 1996) and simultaneously mentioned that the members in a species share same characteristics. These similarities in morphological characters are one of the basis of species identification. Biologists do identify species based on morphological character and this serves to indicate reproductive isolation (Hey, 2001). Most plant species can be easily distinguished by morphological character (Richards, 2010). Textbook does mention about endemic, endangered, and extinct species. Unfortunately, some students attributed species as only endemic. And some other students interpreted the above three types wrongly and concluded that species can be classified only in these three ways.

Students' understanding of species appears to be complex. On one side they attribute biological species concepts to a living organism and at the same time consider species as only animal. Students see species as varieties and at the same time classify species in only three categories: endemic, endanger, and extinct.

It is heartening that students associate concepts of species with organisms' habitat and idea of relatedness. The ideas are close to other standard species concepts like Ecological Species Concepts and Phylogenetic Species Concepts. We can use these opportunities to initiate discussion on alternative species concepts. One student's response

> Species are a particular group of living beings … born through a same kind of source (F/21) reminds us the Buffon's quote:
>
> We should regard two animals as belonging to the same species if, by means of copulation, they can perpetuate themselves and preserve the likeness of the species; and we should regard them as belonging to different species if they are incapable of producing progeny by the same means (Buffon, as translated in Lovejoy 1968 as cited in Mallet, 2010).

Several students rightly pointed out that members of the species share common characteristics and some of them mentioned that individuals of species are of same 'kind'. It is not clear whether students conceptualised these aspects. Some students mentioned criteria of similarities in species characterisation. Some of the students' misconceptions are random and appears to have no connection with textbook content. For example, ideas like species have large population, they are rare, species are microscopic etc.

Implications in teaching

It is observed that students' concepts of species are complex. Therefore, exploring students' concepts in fragmented way would not give actual picture of the students understanding of species. For example, if students are asked to define Endangered or Extinct Species, most students would correctly define them and even mention two animal examples. Therefore, the classroom discussions need to be structured in such a way that students' face conflicting ideas and share their ideas in the classroom.

On the other hand considering the multiple view of species concepts teachers need to address students' varied concepts about species. Each of the concepts can be a potential discussion topic to develop better idea about species. The discussion can be structured to encourage the students' views and at the same time challenge the idea with others. For example, students' ideas of similarities in character of the members in a species can be challenged with the examples where the similarities between the members of the same species or dis-similarities between the two species are very less. This discussion can be extended to morphological identification, which plays a crucial role to identify extinct species.

Conclusions

The paper reports a preliminary analysis of CBSE science and social science textbooks from Class I – VIII on how species concept is introduced as well as Class VIII students' species concepts. It is observed that students' concepts of species has several correspondence with textbook presentation of species concepts. However, students have not understood many concepts and at the worst misinterpreted textbook content. Students' understanding seems to be fragmented and incomplete.

The paper cites several of the students' misconceptions and alternative conception of species. However, the study can be extended to larger sample to have better idea about the various concepts. The method of eliciting students' responses was similar to formal examination and therefore unable to check students spontaneous ideas about species. The study is inadequate to provide a coherent pattern in students' species concepts. The analysis of the textbook was an important dimension to explore the sources of students' varied responses. However, the analysis is limited to the chapters which have explicit mention of "species". In addition the graphics presented in the textbooks are also not analysed.

The findings reported in this paper would help structuring more elaborate study on students' and teachers' concepts of species. Finally, we need to encourage and appreciate students' multiple ideas about species and use it as a platform for rich discussion in the classroom.

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"Omne Vivum Ex Vivo"? A Study of Middle School Students' Explanations of the Seemingly Sudden Appearance of Some Life Forms

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We present here a study of 8th grade students' explanations of the seemingly sudden appearance of some life forms that they observe in their day to day experience. This helped us uncover not only students' ideas on this topic that we found were similar to pre-Pasteur notions of the appearance of life forms, and other interesting alternatives, but also some aspects of how they have understood the material in their biology curriculum. We found that merely teaching life cycles of some species did not help students to generalise that life comes from life. We believe this has implications for the biology curriculum at the school level. This study would be of use to teachers and other educators because we need to know what children think about the genesis of life if these ideas are to be addressed. Else they may well continue to be part of their framework even into adult life (there is anecdotal evidence that this is commonplace in the adult population in India).

Introduction

Researchers have long appreciated that children coming into a learning environment bring their own conceptions of the world. These conceptions are not necessarily those of scientists, i.e. those that are accepted as correct by curriculum writers and teachers (Stepans,1985). Several such conceptions across many subject areas have been reported. For example, that seasons are caused by the Earth's varying distance from Sun, that the terms 'energy' and 'force' have the same meaning, (Goodling and Metz, 2011(Adapted in part from New York Science Teacher 2010)) or, to cite from biology, that micro-organisms are mini-versions of animals such as beetles or worms and have characteristics such as head with facial features or limbs with hands. (Byrne et al., 2009; and references therein; Jones & Rua, 2006) and that dinosaurs, humans, and caveman coexisted.

Students form these ideas from a variety of sources. Simpson & Arnold (1982), Viennot (1979) (no reference listed) point out that "Pupils do not learn only within the classroom", they gather incorrect ideas from chance remarks by adults, television, popular science publications, advertisements and ill-taught or misunderstood subject matter in school (as cited in Stahl,1992). Folklore also contributes to incorrect conceptions (Stahl, 1992). Stahl gives examples of pupil's remarks in class based on folklore in Israel, "Ticks are born as skin and bone". Only when they begin to drink blood, they become alive (grade 6)."Lice are created in people's hat when very hot winds are blowing" (grade 5). These are examples of belief in spontaneous generation, still a part of folk belief in Israel.

Additionally, in their attempts to make a coherent picture from bits of information that conflict with their preconceived ideas, students often create ingenious explanations. For example, when taught that the Earth is round, which conflicts with their experience of the Earth as being flat, they build up, among others, a two-Earth model - the flat one they live on and a round one in the sky (Vosniadou & Brewer, 1996).

Folklore of course varies from region to region. Stahl (1992) points out that in studies involving folklore in non western populations he found next to nothing about the possible impact of culture on the beliefs and concepts of school children relating to science.

Belief in spontaneous generation of life appears to be fairly commonplace in India, as suggested by anecdotal evidence. Several grocers, and other adults, when we asked them how pests suddenly appear in stored food grains, explained that agricultural products get worms/insects in them as a result of the damp air coming in contact with the food product which 'forms' the pest or, more elaborately, that moisture in contact with grain forms eggs which develop into the insects/worms. We also found in an informal survey we conducted of 12 adults with college degrees, that they believed in spontaneous generation of life. All but two of them had a science (other than biology) or engineering degree, 2 had non-science Master's degrees.

Perhaps this is not entirely surprising because experiences shape our view of the world, and the experience (of seeing worms/insects develop in old grain) combined with the fact that parts of the life cycle remain out of easy access to observation leads people to the idea of old grain turning into worms or insects. Indeed, historically, through the middle ages and till the late half of the nineteenth century it was believed that some life forms arose spontaneously from non living matter. Maggots arising spontaneously from rotting flesh, or mice generated from sweaty clothes, were among several recipes that were offered. For a summary of the historical development of ideas explaining the appearance of life forms see (Padmanabhan, 2011 and Corrington, 1961).

Given this background, and that the growth of children's conceptual understanding in science closely parallels the history of science (such as pre-Galilean notions of force) we decided to test what explanations middle school students gave for the seemingly sudden appearance of life where none was seen before.

Here we report the results of a study we conducted with middle school students who had just started grade 8, and who had had several years of formal instruction in biology. Specifically, we investigated whether they held a belief in spontaneous generation, or abiogenesis. We present a qualitative analysis of students' responses and discuss the results.

Methodology

Precursors to this study

We had, in the science classes we conduct for grades 6 through 8 as part of a larger program of curriculum development, got an inkling that some students (from schools other than those in the current study) might believe in the spontaneous generation of life as an explanation for the seemingly sudden appearance of life that they observe in their day to day lives (such as weevils and moth larvae in old grain, or parasites such as head lice).

Participants

This study was conducted with students from two schools in Mumbai; it was a convenience sample. The sample of 175 students (98 boys, 77 girls, average age = 12.3 years) were in the first few weeks of their academic year in grade VIII. They came from varied linguistic backgrounds; a majority (about 80%) came from quite highly educated families where a parent was a doctor, engineer or scientist (Sesha Babu, 2012).

Prior to our study, the students had already been exposed to life cycles of mosquito, housefly and silk moth in their school curriculum, which is developed and prescribed by the Central Board of Secondary Education (NCERT, 2006 & NCERT, 2003).

Data sources and analysis

The data were collected in two steps: first a written test, or worksheet, consisting of 3 open ended questions was developed and administered to all students of the sample. It consisted of three questions: Q1 asked how mosquitoes, which live for only about a month, and need water to lay their eggs, appear long after the rains have stopped and the dry season sets in. Q2 asked if, and how, intestinal worms can come from eating too many sweets. Q3 asked from where moss suddenly appears when the rains come. An open ended question can catch the authenticity, richness and depth of response (Cohen, Lawrence and Morrison, 2007) that a multiple choice test can often miss. Thereafter detailed, open ended, semi structured interviews were held with a sub sample of 54 students selected on the basis of their written responses in the worksheet. Both the written and oral responses were analysed qualitatively.

Step 1 (Written responses)

The test was conducted in the two schools within a period of 2 days (dates 17th and 19th April 2010). The students had an entire 40-minute class period to complete the test.

A preliminary analysis was done by randomly selecting 25 of the 175 worksheets, each of which was separately analysed by three researchers from the research team. The written responses to each question were examined for indications of either spontaneous generation or biogenesis as an explanation. It was found that categories other than these two were needed; these were arrived at after detailed discussions among the entire research team: unclear responses' that were further grouped into those possibly tending towards spontaneous generation (UA) and those that tended towards biogenesis (UB). For example a student's written response that 'when we eat sweets some particles remains and worms comes [sic]' was marked as UA.

The data were analysed in this way iteratively, and more categories emerged such as 'transformation' (where one form of life transforming to another was offered as an explanation) and 'not addressed' (a response given, but one that completely failed to address the question). Another clear sub-category emerged for Q3 - students have simply given 'suitable conditions' or 'right conditions' as explanation for the growth of moss, without addressing the question. They were categorised as NAc separately from NA.

Differences between individual researchers in assigning responses to categories were sorted out through discussion. In the first round of assigning categories, there was disagreement in 16 out of 75 responses between one of the researchers and the other two. There were only three instances when there was disagreement among all the three researchers about the correct category that the response belonged to; a detailed discussion successfully sorted out the differences and firm categories were assigned for which there was agreement between all researchers. Responses from the remaining worksheets were analysed and grouped into the categories that emerged from the preliminary analysis (Table 1).

Categories	Examples
CA – Clear idea of spontaneous generation of life.	Sweets are made by adding some chemicals which are not digested and turn into worms.
CBT – Response clearly indicating biogenesis but explanations involving one microbial form transforming into another.	Some bacteria enter our stomach, feeds on sweets and “become worm”.
CB – Response clearly indicating biogenesis.	Mosquitoes lay eggs in stagnant & dirty water.
UA–Response unclear but tending towards spontaneous generation.	Sweets contain sugar which cause worms to grow.
UB–Response unclear but tending towards biogenesis.	Sweets contain lot of sugar. Harmful insects land on them and dirt sticks to sweets.
NA – Not addressed.	Moss requires water to grow.

Table 1. Categories of students’ written responses with examples

Step two (Oral Responses)

Those students who gave unclear responses as well as those whose explanations indicated that life can come from non life forms, such as 'chemicals in the food form worms' were selected for the interview for further probing. An interview protocol was developed to probe students' thinking, starting with their written responses but going well beyond it. Since the interview questions were dependent on students’ written and subsequent oral responses, the protocol was not a strict sequence of questions but a guideline that attempted to cover a wide range of student responses. The protocol noted that when a student postulates an explanation, the mechanisms they conceive of in that scenario (for example, if bacteria enter intestines to form worms, how exactly does this happen?) were to be probed.

Prior to the interviews, practice sessions were held among the research team. This also served to train those members who had not had much prior experience in interviewing school students. Care was taken that no cues (either verbal or through facial expression or body language) were given, since it has been our experience that students are adept at reading such cues and tailoring their answers accordingly. This exercise also served as a pilot run, and helped to fine-tune the protocol.

Each student was interviewed by one of the 3 members of the research team. The interviews were audio recorded, and on occasion notes were taken as necessary. Students were given the option of making sketches or drawings to explain their ideas. The interviews typically lasted 40 minutes but ranged from 18 to 50 minutes. The responses in the interviews were also analysed iteratively and categorised; some additional categories were found necessary.

Results

Written responses (worksheet)

The results are summarised in Table 2. The category 'Miscellaneous' (Misc.) describes responses that could not be assigned any of the other categories in the table. To Q1, a majority of students in the survey (87%) responded that mosquitoes come only from (mosquito) eggs. These students have conjectured the following as possible explanations: that mosquitoes migrate (from a place where water has not completely dried up); some water would still be lurking somewhere in which eggs can be laid; eggs may remain viable over a dry period. The remaining (13%) of the responses included the following as explanations: mosquitoes come from dirty surroundings, infected person, from dirty water, from waste and garbage.

In response to Q2 (on intestinal worms), 15.4 % of students responded that worms come from worms but an almost equal number of children said that worms can be formed from bacteria, micro-organisms, ‘germs’ and housefly eggs, i.e. a transformation of one species to another. Nearly 10 % of students responded that worms can be generated from eating excess of sugar through ‘some chemical reaction’. 26.8% students responded to the second part (how) with statements that were completely irrelevant such as “yes, eating a lot of sweets can cause worms in the stomach because sweets contain a huge amount of sugar which helps in causing worms. Due to which it may lead to diabetes. It must be strictly restricted to heart patient [sic]. The sweets may contain air also”.

	Q1.				Q2.				Q3.			
	A	B	Total	%	A	B	Total	%	A	B	Total	%
CB	86	67	153	87	18	9	27	15.4	51	28	79	45.1
CBT	0	0	0	-	18	10	28	16	4	1	5	2.8
CA	1	1	2	1.1	6	11	17	9.7	2	2	4	2.2
UA	0	1	1	0.5	11	9	20	11.4	12	0	12	6.8
UB	9	0	9	5.1	11	8	19	10.8	8	3	11	6.3
NA	7	2	9	5.1	34	13	47	26.8	17	26	43	24.6
Nac	0	0	0	-	0	0	0	-	7	11	18	10.3
Misc.	-	1	1	0.5	5	12	17	9.7	2	1	3	1.7

Table 2. # of written responses in each category shown school wise (# of students in School A=103, School B = 72)

In Q 3, in which students were asked to explain the appearance of moss during the monsoon season, 45.1% of responses state that moss comes from moss or 'particles' or spores of moss in air; 10.3 % responded by stating that the moisture and temperature provides 'suitable conditions' for the growth of moss without clarifying from where the moss appears (NAc) - “Moss is like algae and fungi and it needs water to grow”. A further 24.5 % were categorised as NA “Moss is green in colour and slippery” or “The moss may have appeared because of the rains as in rains many insects breed and all around the atmosphere is wet. So the moss start appearing in the rain.”

Oral Responses (interviews)

It has been our experience that students of this age group are not very expressive in their written responses. In this study too, we found that their oral responses were more articulate and elaborate. Apart from a greater comfort level with oral expression compared to writing, this was probably because it was a dialogue with the interviewer who encouraged them to add details, qualify their answers etc. Students' responses are summarised in Table 3.

96.3% of responses (not respondents, as students typically put forward more than one possible solution) to Q1 were that mosquitoes come from eggs laid in water.

In 35.2% of responses to Q2, students postulated that bacteria, germs, body cells and microbes can form worms. It was found that some students confused the terms worms and germs, and seemed to have vague notions of what these terms meant, despite having been introduced to germs in lessons on hygiene. 12% of the responses were CA - that worms can be formed by toxic substances, chemicals in sweets and preservatives added to sweets etc. 13.6% of responses fall into the vague category – spoiled water, 'bad quality' (of food), uncovered food, toxic substances and unclean surroundings can lead to worms, without postulating a mechanism.

In 67.2% of responses to Q3, biogenesis was put forward as an explanation. 13.8% of responses explain that moss can be formed through some chemical means using rusted iron, chemicals in paint and acid rain. 13.8% of responses fell in the NA category.

Categories	# of interview responses		
	Q1	Q2	Q3
CB	51	40	39
CBT	0	44	0
HYBRID	0	3	3
VAGUE	0	17	0
CA	1	15	8
NA	2	6	8

Table 3. Interview responses

Discussion

We note that there are differences in the percentage of responses that fall in the CB (clearly biogenesis) category between Q1 and the other two questions. We concede that Q1 was somewhat leading in nature; however, we note that students had already learned the life cycle of the mosquito in their schools in an earlier grade and we gave no new information in the question.

In contrast, Q2 described a situation the respondents had not encountered in their school curriculum - the life cycle of intestinal worms. However, students are likely to have heard the 'causal' link mentioned in the question (many parents and doctors, as reported by the students during interviews, tell young children that worms can be formed in the 'stomach' due to eating an excess of sweets, possibly in a well intentioned effort aiming to discourage children from eating too much candy). It is instructive that the responses indicate blind/uncritical acceptance of what is told, and that the life cycles they have been taught has not been generalised to *omne vivum ex vivo*. This is also true of the responses to Q3, where in spite of having been introduced to mosses, there were as many as 14% falling in the CA category. We also note that during the interview, students typically gave multiple explanations falling in different categories without any of them being given primacy.

One of the weaknesses of this paper is that our sample schools are nationally atypical – our participant students come from well off and educated families. Chudgar & Quin (2012) point out that such socio-economic factors may be related to students' academic achievement. It is therefore instructing that we find belief in spontaneous generation and transformation among such a group despite years of formal instruction in biology. Presumably this would be even more widespread in a representative sample of students in the country.

It would have been interesting to examine why students who clearly gave biogenesis as a response did so. This study did not address this question at all.

One of the strengths of this study is that it is done on a fairly large scale, and done in two steps with interviews following written worksheets, which allowed the researchers to probe students thinking more thoroughly. Both steps used the open ended format, so that many categories of responses other than what the researchers had anticipated emerged.

Concluding Remarks

This study shows the explanations Middle School students give for the appearance of life forms. Interestingly, explanations of biogenesis, spontaneous generation, and transformation were all put on an equal footing by students, particularly when they encountered a situation that they had not encountered in their school textbooks. Merely teaching them life cycles of butterfly, mosquito and silkworm has not served to enable them to generalise that life comes from life including, smaller life forms and microscopic organisms. Clearly the biology curriculum needs to address that this is true for all life forms including microscopic organisms.

While one cannot rule out unfamiliarity with language as a possible cause of some students' confusion between worms and germs, an inadequate treatment of this material in the school curriculum is likely the main cause. An adequate treatment would address issues of language.

Finally, the authors cannot help but wonder if, as prerequisite to teaching evolution, it is not necessary to address ideas of spontaneous generation and transformation; after all, if life can form in these ways, what is the compelling need to accept the theory of evolution?

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Strand 3

Curriculum and Pedagogical Studies in STM

Characterising Work-Contexts from a Mathematics Learning Perspective

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Based on an ongoing larger study the present paper makes an attempt to develop a framework for characterising the work contexts of school going working students, which create affordances for learning mathematics. The paper argues that the characteristics of work contexts that have a bearing on learning mathematics include the diversity of goods that students handle as workers, the linkages on the production network that are visible to them and the sense of ownership that they have for the work. The analysis is drawn from semi-structured interviews with students. Students' awareness and knowledge about the earnings from their work and responses to questions about the fairness of earnings varied and could be related to the three characteristics identified.

Introduction

Research studies in the past on everyday mathematics have documented that mathematics learning and problem solving ability among school students develop also from their participation in small scale economic activity (Abreu, 2008; Bose & Subramaniam, 2011; Nunes, Schliemann & Carraher, 1993; Rampal, 2003; Resnick, 1987). Researchers have argued that children and adults who are engaged in everyday mathematical activities and commercial exchange often develop effective context specific problem solving ability that could be used for effective mathematics learning in the classrooms. The contexts of such engagement are diverse and consequently, the extent and type of mathematical knowledge that students acquire outside school can be expected to show diversity. For example, Khan's comparative study (2004) on the strategies used by *paan* (betel leaf) and cigarette sellers, newspaper vendors and school-students, indicated that of these three groups, *paan*-cigarette sellers had to negotiate diverse kinds of calculation because of the diversity of goods and quantities that they sold involving different units which helped them gain better computational facility.

In this paper we address the issue of diversity of experiences of out-of-school work contexts and its relation to mathematical knowledge. We draw on findings from an ongoing research study aimed at characterising out-of-school mathematics knowledge and its relation to mathematics learning in school. Our study was of Grade 6 and 7 students from two municipal corporation-run schools located in a large low-income area in Mumbai. As a unique feature, this area has a vibrant economy in the form of house-hold based workshops and small scale factory and manufacturing units, which provide employment to the dense population living in the locality. Even within a single class, we find students engaged in a variety of income-generating work both within the house-hold and in the neighbourhood. The question that we address here is how do different kinds of work create affordances for learning in general and learning mathematics in particular.

House-hold based small scale production, like factory based production, is also subject to the processes of fragmentation, routinisation, mechanization, and deskilling, resulting in consequent demathematisation of the knowledge within the community. At the same time, there is a counter trend to these processes through the enterprise of individuals and groups seeking out avenues for making a living (Subramaniam & Bose, 2012). Some kinds of work involve diverse interactions with people and material, leading to greater opportunities to acquire knowledge and skill. Thus we find economic activity that is varied and calls on a range of knowledge and skills as well as activity that is routinized, making little demand on skills and knowledge. One of the factors is the nature of work itself, which may be difficult and demanding, or repetitive and mechanical, or characterized by diversity. As mentioned earlier, it has been found that diversity in the type of goods sold allows paan-cigarette vendors to acquire greater proficiency in arithmetic skills (Khan, 2004). Another factor, which is especially relevant with regard to the affordances that the work provides for mathematical learning, is the extent of exposure to the network of production that the work is embedded in. Each work is part of a production chain or network and participants in the work have awareness and knowledge to different extents of the forward and backward linkages in the production network. A third factor is the feeling of ownership that participants have towards the work that they are involved in. Children whose close relatives, friends or families own businesses have a stronger sense of ownership of the work, in comparison to those who work merely for wages. We hypothesize that the greater the exposure to the production network, the more the opportunities to acquire mathematical knowledge. Similarly, the stronger the sense of ownership, the greater is the exposure to linkages in the production network, and more the opportunities to acquire mathematical knowledge. All the three factors of diversity of the nature of work, extent of exposure to linkages and feeling of ownership, can be expected to determine the nature and extent of mathematical knowledge that children acquire. In this paper, using qualitative ethnographic data collected in the study, we explore these three factors in order to understand the opportunities that diverse work environments create for learning mathematics. Finally we analyse students' responses to one domain where mathematics is invariably applied, namely, to estimate or calculate earnings and to determine if a piece of work has a fair earning outcome.

Methodology

The larger ethnographic study, which forms the setting for this article, was conducted in several phases. In the beginning, the researcher (i.e. the first author) started with the classroom observations of Grades 5 and 6 of two municipal corporation-run schools. This was followed by informal discussions with the students to get a broad picture of the nature of their daily activities that have aspects of mathematics and the nature and extent of their everyday mathematical knowledge. This helped in getting an initial understanding of the variation in children's out-of-school mathematical knowledge, opportunities available to gather such knowledge as well as the extent of their involvement in economic activities.

The present work is backgrounded by the researcher's (i.e., first author's) extended interaction with the community for about two years. A total of 31 students were chosen randomly from Grade 6, to form the original sample out of which a detailed study was carried out with a sub-sample of 10 students. The present data is drawn from semi-structured interviews with 17 students (all 10 students from the sub-sample + 7 students who were keen to take part, but were not part of the original sample). The interviews focused on their knowledge about the work that they were engaged in. The interviews lasted between 24 minutes to 52 minutes. For the preliminary analysis of these interviews, we chose 8 students who had varying extents and kinds of engagement with the work contexts. All the 8 students whose involvement in work is discussed below, had just finished Grade 7 at the time of the interviews. Interviews were transcribed and transcripts reviewed for what they indicate about the nature of work students are involved in, and what they know about aspects of the work. The analysis and discussion below is drawn largely from interviews, supplemented with data gathered during visits to the work places. Pseudonyms have been used throughout.

Characterising Work-Contexts

In this section we discuss the different kinds of work in which the sample students are engaged with respect to the following three aspects: (i) diversity in the work in terms of articles made or sold, and diversity of customers dealt with (ii) awareness of linkages within and across the work-domain, and (iii) sense of ownership of the work.

Mobile Phone Repairing (Salim, 14 Year Old Boy)

Several young men in the neighbourhood are involved in this work. Salim got into this work by spending time in his friend's shop observing him repair phones. His work-context requires him to interact with different people starting from negotiations with a variety of customers who bring the defective mobiles. Salim is led to diverse sites in connection to his work, for example, to places where he buys mobile phone spares, parts, repairing tools, electrical appliances like soldering machine, etc. He has knowledge of different mobile-parts and their functions; he knows the costs of both original spare parts and low-cost substitute parts that are made locally. He travels to distant markets in the city which sell spares at lower prices than the neighbourhood shops. Knowledge of a range of products and brands and their prices is required for his work. He has to quote a price for a job by guessing the customer's paying capacity. This helps in deciding whether to use an original part or a low-cost substitute, keeping in mind the expected profit. Quoting a price may often call for mental computation of quantity and price of required parts and the time required to carry out repairs. Salim also has to keep in mind what other shopkeepers in the vicinity are charging for the repair work. Thus Salim's decisions are similar to the ones made by his friend, the repair shop owner.

We find that Salim has an awareness of different aspects of the entire job and has had exposure to linkages in which the work of mobile phone repairing is situated. At present he works with his shop-owner friend, but he plans to run a similar business all by himself.

Dyeing work (Rizwi, 13 year old boy)

Rizwi helps his elder brother and father in their 'dyeing' workshop where three more employees work. The workshop is located in a tiny first floor room of a rented house while the ground floor room is used as the living room and kitchen for the family of seven. The work involves block printing of patterns or "logos" on textiles, school bags and gunny bags or sacks and is referred to as dyeing work. Rizwi showed awareness of linkages in which this work is situated, which include the place from where the printing orders come, place where the design is drawn using computer graphics based on the logo template, the place from where raw materials are procured, and the place where delivery of the printed material is made.

Rizwi knows about the different raw materials used in the work, viz., stoppers (blocks used in printing the design), dyeing frames of varying sizes, different dye colours, thinner, adhesive, etc. He explained that different sizes of the dyeing frames and stoppers are made by carpenters on order. Rizwi explained that the typical frame-sizes are 16"x12", 28"x12" making of which cost between Rs 2000-3000. Two types of colouring material producing either shining or mat-finished effect are used. Rizwi knows the prices of the colours, thinner, coating material, etc. He knows which colours are to be mixed for a particular colour or shade to emerge and the proportion in which they are mixed.

Bulk orders for printing logos on the school bags for municipal corporation run schools in Mumbai are usually placed in the months of March, April and May. For Rizwi, this heavy work pressure coincides with the preparation for the year-end examinations. In the peak season of work, the daily turnover varies between Rs 2000 to 3000. The workers get a monthly salary of Rs 4500 with an option of withdrawing upto Rs 500 per week which is then adjusted against the salary. Rizwi gets around Rs 100 per week for pocket expenses.

Rizwi informed the researcher that he makes a choice of the suitable dye-frame and stopper of a particular size by looking at the logo design to be printed in a given task. The unit used for measuring is inch. When the interviewer (researcher) asked Rizwi to make a 'guess' of the dimensions of few objects lying around, viz. voice recorder, desk, note-books, he gave nearly accurate answers – all in inches. It is interesting to note that inch is a measuring unit that is not taught in schools.

It was evident from Rizwi's response that he felt a sense of ownership over the work. When asked if he helps the workers, he said, "*apna kaam hai to madad to karna padega na*" [*it's our work so need to help*]. His statements also indicated a concern about optimal use of resources and time, "*colour-valor jo hai, cutter-wutter saman laker de deta hoon, karigar jayenge to time laga dete hain na... isiliye humlog jate hain saman kharidte hain...pagar chalu hai na...*" [*I go to buy colour, cutter, whatever, if the workers go they take long and they are being paid (for their time)... so we go and buy stuff*].

Ready-made garment selling (Dameen, 13 year old boy)

Ready-made garment selling is a popular business that is seen in most localities. We interviewed with Dameen who visits his father's ready-made garment shop in downtown Mumbai on Sundays and on holidays. Dameen knew the connection between garment size and age: that frock-size 22 is for 4-year olds while, size no. 30 for 10-12 year old girls and 32 for girls who are 13-14 years old. Knowledge of profit margins of different sizes helps in making decisions about quoted price and discount at the time of bargaining with customers. The frocks that he deals in sell for about Rs 70-160 with a profit margin of Rs 5 to Rs 40 depending upon the sizes. He claims that sizes like 30, 32 incur loss because their making charges are more in comparison to other sizes and hence the profit margin is less. Dameen's job hence entails quoting price and discount to customers while ensuring a reasonable profit. He also takes up other responsibilities in the job: keeping track of stocks and sales, and maintaining accounts. Dameen is familiar with some of the backward linkages: his uncle runs a *zari* workshop where designs are made and stitched on to clothes. The newly-stitched dresses are then sent for "thread-cutting" (also called "*fees*" cutting) and subsequently come to Dameen's shop for packaging and selling.

Tailoring (Sohrab and Perzo, 14 year old boys)

Tailoring is one of the most common occupations in the locality. The work of tailoring as a whole is complex and involves stages of skill development from novice to apprentice to master. During the interview, Sohrab described how a novice first develops hand-stitching skills and then learns to use a sewing machine. Sohrab explained that he worked in a tailoring workshop to learn stitching following his father's suggestion as a way of productively using his spare time. He described that novices begin as 'helpers' who assist other workers before they are given stitching work. Although Sohrab did not earn anything from the work initially till he learnt stitching, all this was taken as part of his learning.

Tailoring is also a work that is compartmentalised and fragmented. For example, in garment stitching work, a group of people (mostly novices) would stitch only collars and cuffs of a shirt, while others with more experience (apprentices), do complex work like stitching all the parts together, while a third group puts buttons and yet another group removes threads (discussed below) from the newly stitched shirts. This is followed by ironing of clothes and packaging work. Unlike dyeing and mobile phone repairing work, garment stitching work is completed by putting together smaller, compartmentalised tasks which are done at different workshops with owners having linkages only to the next stage of the work and practically no linkage with the market network.

A worker usually works at a location with materials that are provided to him. He does not deal with the customer. *Masters*, who get the orders, cut the cloth in bulk and distribute the pieces to 'compartmentalised' workshops. Raw-materials like threads and needles are provided to the workers. The stitching work chain ends with the delivery of stitched materials to the dealers.

Workers like Sohrab get wage based on the number of pieces they stitch, for example, 50 *paise* to a *rupee* per piece of work, while there are workers who get monthly wages, which may still be quite meagre. For example, Perzo explained that he worked in a tailoring workshop along with 4 other children of similar age whose work involved stitching garments. Perzo explained that their monthly salary ranged between Rs 1200 to 1500 depending upon how fast they could stitch. Neither Sohrab's nor Perzo's work required knowledge of linkages on the production chain or handling diverse goods. They were paid workers almost at the bottom of the hierarchy of workers and unlike Salim, Rizwi and Dameen, did not have a sense of ownership of the work.

One of the most common house-hold occupations for women is thread cutting (or "*fees*" cutting) work referred to above – a part of the garment manufacture chain. This work involves removing the extra threads from the newly-stitched garments. This does not require training, bigger space or equipment. Generally sharp-edged cutters/knives are used. This is an example of a task on the garment manufacture chain that does not require awareness about other tasks beyond the immediate engagement. It is a routinised activity that does not demand skills or knowledge from the workers.

Stone fixing work (Sakhi, 13 year old girl)

Stone fixing work involves putting coloured stones (usually up to 4) on ear-rings, pendants, rings, buckles, and *mangal-sutra* (a kind of necklace). Workers involved in this work do not need to have knowledge about other parts of the production network. The worker needs to only focus on her immediate task. It is also routinised work and does not call for skill or knowledge. Sakhi, a 13-year old girl who has been doing this work along with her mother for more than three years, has now become adept with the routine arithmetical calculations involved in the task – generally 6 pairs or 12 pairs of ear-rings are stuck in a card, with total number of pairs being 1 gross (= 12 dozen) bunched together. The wage is calculated per gross of pairs. The order comes from a middle-man who provides all the materials required for the task and also collects the finished-products and makes the payment. The workers do not have to deal with customers separately or sell the goods. This makes such less-paying jobs preferred as it is seen as an opportunity to supplement income by working at home.

Rakhi work (Shahnaz, 13 year old girl)

Rakhi making is a common household seasonal work in which women are mostly involved. *Rakhi* is a decorative wrist-band tied on a brother's wrist by a sister during the *Raksha bandhan* festival in August. The raw material for making *rakhi* is delivered at the worker's home by the middle-man who collects the finished product and sends them for packaging. *Rakhi*-making work begins as early as in February. Similar to stone-fixing work, *rakhi* making work does not require the awareness about the aspects or other linkages on the production network. The workers do not have to deal with retail sellers or retail customers.

Latkan (door-hanging) work (Gulnaz, 14 year old girl)

Latkan is a decorative door-hanging made up of different, colourful sequins of various sizes strung on a thread following certain sequence. Gulnaz visits her aunt's place next door where neighbourhood women are involved in this work. For this job too, middlemen bring the order and raw materials, collect the finished products and make the payment. Workers like Gulnaz only need to focus on the task at hand and not on other linkages on the production chain. Like *rakhi-making* and *stone-fixing* work, *latkan* making is also routinised work and requires knowledge of only a small chunk of a larger process.

Mathematics of Earning

Engagement in economic activity always involves making decisions relating to income: what work to engage in, how much time to spend, what the possibility of income is, how steady or reliable it is and so on. Calculation is an important input in the decision making process: calculating costs, incomes, opportunity costs, optimising earning, etc. Calculation is also involved in making a judgement about the fairness of a deal. These aspects are important to take account of in mathematics education since judgements about personal and public finances often need one to apply mathematical knowledge. In the interviews we asked students about how much they earned and if they were satisfied with the earning. The responses were diverse. We noticed that the responses were related to the three factors that we have mentioned earlier as characterising work contexts, namely, diversity of goods and customers, awareness of linkages and a sense of ownership in relation to the work. Complex mathematical calculations and optimisations are used in work that have more linkages within and across work-domains and deal with diverse goods and prices. Workers with a sense of ownership about their work also acquire a sense of control over their works as was apparent from Salim, Rizwi and Dameen's descriptions. In case of other students, we noticed a reluctance to use mathematical calculation to engage with questions of fairness, and in some cases inappropriate use of calculation.

We reproduce an extract from the student-interviews below. It is taken from the interview with Shahnaz, who was involved in *rakhi* making at home.

[*for all the transcripts given below, alphabets 'R' and 'S' stand for researcher and student respectively; the numbers on the left are the line numbers from the original transcripts while translation into English is provided on the right*]

185 R: To ab, paisa kaise milta hai?	*so now, how much wage is given?*
186 S: paisa gurus ke hisaab se milta hai/	*wage is given according to "gurus" (i.e., gross)/*
187 R: matlab, ek gurus ka kitna milta hai?	*so, how much for a gurus?*
188 S: ek gurus ka pandrah rupaya, pandrah, barah, aise, dus/	*for one gurus, fifteen rupees, fifteen, twelve, like this.., [maybe] ten/*
189 R: poore ek gurus ka?	*for a whole gurus?*
190 S: Haan/	*yes/*
191 R: matlab ek sau chhauuwalis rakhi ka pandrah *rupaya milta hai?*	*so, for one hundred forty-four rakhis you get fifteen rupees?*
192 S: Haan/	*yes/*
193 R: achha, yeh, tum iss rate se khush ho? Ya aur kam milna chahiye, jyada milna chahiye, kya lagta hai?	*ok, so are you happy with this rate? or, you should get less, more, what do you feel?*
194 S: pandrah, pandrah bees rupaya milna chahiye/	*fifteen, fifteen twenty rupees should we get/*
195 R: pandrah bees rupaya milna chahiye? Matlab kam milta hai?	*should get fifteen twenty rupees? so, getting less?*
196 S: Haan/	*yes/*
197 R: accha, to wohlog ek rakhi kitne rupaye mein bechte hain?	*so, how many rupees do they sell one rakhi for?*
198 S: ek rakhi wohlog paanch,dus rupaye mein bechte honge/	*they must be selling one rakhi for five, ten rupees/*
199 R: Paanch-dus rupaye mein bechte hain? Aur tumko, tumko kitna milta hoga ek rakhi ke liye?	*sell for five-ten rupees? and you, you get how much for one rakhi?*

200 S: humko, ek rakhi to aath aana bhi nahin milta hoga/ *we don't even get eight aana[1] for one rakhi/*

Shahnaz was asked to calculate the selling price of one gross of *rakhi*, but she could only tell the price of one dozen – Rs 60 (one *rakhi* is sold for Rs 5). The researcher helped her in finding the price at which one gross of *rakhi* is sold – Rs 720 for which she only gets Rs 15 or less. She could not calculate the amount she gets for making a single *rakhi* – which is about 10 *paise* (one-tenth of a rupee). The payment for making the *rakhis* is held up till all the *rakhis* are sold out close to the festival, and workers like Shahnaz get payments only after a delay of a few months. She said that a detailed account is maintained in the *chaukri* (diary).

Our discussion with Gulnaz also highlighted the low wage that workers get: she gets Re 1 per *latkan* which is sold for Rs 50 to the customers; but she seemed to be satisfied with the amount she got. Similarly, when Sakhi who is involved in stone-fixing work was asked if what she was paid was satisfactory, she explained that it was since there were other costs added to the final retail price viz. transportation cost, cost of making and polishing the jewellery and finally the retailer only gets 50 *paise* margin per pair of ear-ring. Apparently, Sakhi gets one-fortieth part of the price at which the ear-rings are sold. The fairness issue of wage distribution failed to trigger any definite response from her as well like other students involved only in the low-paid fragmented chunks on the production network.

Discussion

We found among our respondents that some were very aware of different aspects of the work, and felt a sense of ownership with regard to the work. These were also the respondents who spoke in some detail about their work, about prices, earnings, wages, discounts, etc. Examining the characteristics of the different kinds of work revealed that the most important of these from the point of view of opportunities to acquire mathematical knowledge are diversity in the work-context, awareness of linkages in the production network and sense of ownership about the work. For example, Salim, Rizwi and Dameen felt a sense of ownership unlike Sohrab and Perzo and were aware of diverse aspects of their work as well as the forward and backward linkages that their work had. These students did not participate in the work primarily for the income, but also to pick up useful skills which are valued as they are perceived as opportunities to get into income-generating practices in the future. Salim, for example, takes pride in knowing about both kinds of work – mobile phone repairing as well as garment stitching work (Salim's father does the latter work with the help of three employees and Salim visits his father's shop often). Gaining such knowledge is considered to be important. Often children are advised by their elders to use their 'leisure' time for learning new work and for developing new skills and thereby making 'proper use' of the time. Besides the usual reason given that children work to supplement the family income, the goal of learning something through work is important for all the children whom we interviewed.

Women in the community and school going girls are mostly involved in those kinds of work which require working at home without requiring to know about other aspects or linkages on the production chain. The workshops are mostly run by men and interviews with girls like Shahnaz, Gulnaz and Sakhi indicated that work perceived as less 'technical' are given to women who do them at home taking help from other women. 'Isolated' and fragmented tasks are kept for women. Managing house-hold chores is an essential part of the daily routine women and girls and some spare time is used to generate some income on the side.

Thus, for some children, especially girls, the opportunities that the work context provides for learning are severely constrained. We believe that the characteristics that we have identified in this paper are important factors that determine the extent of such opportunities for learning in general as well as learning mathematics. An indication of this is the sparse and limited responses that we got from students with limited exposure and no sense of ownership for the work to questions involving the application of mathematics to questions about income and fairness of earnings.

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1 'aana' is an old currency unit no longer in use but still part of daily parlance. 16 aana = 1 rupee = 100 paise; hence, 8 aana is used for 50 paise.

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Innovating Teacher Education: Mathematics at the Enterprise, University and School Math-Eus Project

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This project focuses on the idea of meaningful learning to advance mathematical knowledge focusing on algebra. This interdisciplinary project has been developed with pupils from a lower secondary school (9th -grade), students from the master's program in mathematics education at the university and engineers from a local enterprise. The research exercise has been carried out by the master's students and all participants have been regularly planning and discussing the implementation of the project. The results show the importance of using contexts and elements from industry as a basis for the elaboration of meaningful algebraic problems. The engagement of all project participants generated discussions which can improve the mathematics understanding and amplify the awareness of an ecological mind.

Introduction

Recent research in mathematics education and socio-cultural approaches to learning, have focused and insisted on the importance of students making sense of what they learn in school (Säljö, 2001). It is in fact the understanding of the subject matter that motivates, supports and engages them in advancing mathematical and science construction of knowledge (Bradal, 1997; Hoyles, Noss, Kent & Baker, 2010).

From this perspective, teacher education is a central arena for discussing and proposing activities related to meaning making in the mathematics classroom with future teachers. The idea is that these prospective teachers (at the master's level) need to take the classroom as an object of study. In order to do it, they observe what is going on in the lesson, analyse the interaction between teacher students and the subject matter - in this case mathematics - and focus particularly on the tasks proposed by the teacher and solved by the students. These ideas have been in operation since 1995, when the MERG (Mathematics Education Research Group) project was elaborated and implemented, in the master's course *Teaching and Learning Mathematics*. In this *first generation* the project had as the main aim, to introduce future teachers to research, focusing on the context where their future professional activities would take place: the classroom. An inquiring/analytical position was introduced and some research methods as well in order to give teachers/students some tools to analyse in a more systematic way data not only collected in the project itself but also to be used in their future practice as teachers (for more details see (xxx, 2008)). Even though this was an innovative project at that time, in other contexts teacher education for research based practice had been implemented earlier, for example in Finland (Westbury, Hansén, Kansanen and Björkvist, 2005).

Background

After sixteen consecutive years of MERG project implementation, each year including a new group of master's students focusing on the analysis of interaction between teacher pupils doing mathematics on different school levels and contemplating a wide diversity of topics included in the national curriculum, something should be changed. What drew our attention were the difficulties presented by pupils working particularly with algebra, when variables have been introduced in expressions to be solved. The passage from numbers to letters in order to express quantities, and the passage from arithmetic to algebra on a high level of abstraction have been identified as some of the crucial points for the pupils. A *second generation* has consequently been developed, since 2010. Even though the basic model continues to be the same, we amplified the scope of the project, including collaborative work with industries.

The MathEUS (Mathematics at the Enterprise, University and School) project started in 2010 as collaboration between two departments, from the Faculty of Engineering and Sciences: *Mathematics* and *Natural Sciences*, at the University of (xxx). More specifically, it consists in an integrated form of developing two projects which until that point had been implemented separately: The MERG (Mathematics Education Research Group) as the local project in its 18th edition, initiated in 1995 and the Lektor 2 project (see details at www.lektor2.no). This last one is a national pilot project related to the Center for Natural Sciences, linked to the Ministry of Education, where the aim is to increase the collaboration between schools and workplaces dealing with natural sciences and mathematics. Because of the interdisciplinary nature of the MathEUS project, it includes participants from the university context, the industrial sector and teachers and pupils from a lower secondary school.

The general aim of the MathEUS project is to elaborate a new model of teaching, articulating practices from work places with theoretical elements of the disciplines from the academic context and new insights emerging from the research done by the master's students. The more specific aim is to create meaningful mathematics activities and tasks to be implemented in lower and upper secondary school. A central idea is to identify the mathematics involved and needed to operate in different professions, for example, those related to the industrial sector which is one of the bases for developing technological societies. Important to mention at this point is how the observation of industrial work "in loco" benefits particularly pupils from multicultural societies, where part of the population is in a process of migration, assimilation and learning a new language. The concreteness of objects, artefacts, machines functioning can be visualized and assimilated as a first step in the process of meaning making. Subsequently those situations can be transformed into problems which will require the use of symbolic and natural language to be formulated and solved. The particular enterprise with excellent conditions to develop this project is related to the transformation of garbage into energy to warm water and to supply electricity. The administrators have as their philosophy to educate the school population in connection with ecological and environmental issues. They open the doors of the factory for pupils' and teachers' visits to promote awareness related to the production of energy based on sub-products generated in households. A pedagogue has been employed full time to create a laboratory, to organize didactical activities for children according to their age and to structure the visits from different schools of the region. In this context master's students have made their observations, elaborated algebraic tasks, contributing in this way to the implementation of new activities in the laboratory.

Design of the project

To attain one of the objectives of this project, which is also intended to expose master's teacher-students to contexts where mathematics is embedded in the activities of men and machines, an ethnographic approach to collecting data has been used. To introduce students to the context of the enterprise, natural observation has been suggested. In this way, they had the opportunity to wander around the space of the enterprise and put questions to the engineer who has been guiding them. This "tour" is a form of appropriation (in terms of learning) of the physical conditions, for example, the position of the machinery and tools in the working space. Based on these observations and, in addition, discussions with the engineer, they have created algebra tasks (see the example below, in Table 1) and word problems involving the use of rules and dealing with variables. Around 90 pupils from an elementary school (9^{th} grade) and eight master's students in Mathematics Education at the university have participated on this project.

Development of activities

Many activities have been planned and developed in the spring semester of 2012, from January until June. At the end of the semester the students presented the analytical report. To start with, a meeting has been organized at the enterprise, including the director, engineers, and pedagogical adviser, to inform them about the nature, aims and development of the project and to plan the activities at the enterprise. Below we present an overview of the main components per week:

- 1: Presentation of the project to students and information related to the visit to Returkraft - U;
- 2: Visit to Returkraft to observe the main activities of employees, (mainly control) and operations done by machines. Identification of possible situations and problems which could require the use of algebra in order to be solved - E;
- 3-4: Elaboration of possible tasks. Discussions and feedback - U;
- 5: Visit to Returkraft and discussion of the tasks with the engineer - E;
- 6-10: Changes and improvements in the tasks and choice of those to be solved by the pupils from the 9^{th}. Grade from Stuenes School - U;
- 11: Work with pupils: Brief information about the tasks, division of the larger group into smaller ones comprising around 10-12 pupils located in small rooms, solution of the tasks. Short meeting with students from the university, including the pedagogical adviser from the enterprise to comment on and discuss experiences - S at E;
- 12-15: Analysis of the solutions by the pupils and review of the literature in this field of research - U;
- 16: Meeting with participants involved directly: students, teacher from school, pedagogue, coordinator of Lektor2, and coordinator of Math-EUS project. Comments related to the tasks and how pupils have

approached them, particularly the main obstacles found. Some improvements to the development of the project have also been proposed - U;

- 16-17: Presentation of Math-EUS paper in a seminar including all students on the course. Feedback from colleagues and teacher - U;
- 18-20: Individual supervision related to the papers presented at the seminar - U;
- 18-23: Preparation of the final paper - U.

It is necessary to mention the complexity of the organization of all these activities, particularly by the inclusion of many participants working in different professional contexts.

Presentation of some examples, comments and findings

From pupils solving tasks

In the figure below we present task 5 which is based on a problem dealing with the use of products from Returkraft. The problem is introduced by a brief text which requires interpretation (see below in Table 1, the original text):

> "One full waste box contains 16 kilograms of trash. It becomes around 9 kilowatt hours (kWh) of electricity.

In the table below three kinds of quantity are presented: the trash, the corresponding quantity of electricity which, when burned, will give the correspondent hours of TV in relation to the same use of electricity.

3. **(Use the table)** How many hours of TV correspond to the burning of 4 kg of waste?
4. Complete the empty cells of the table.
5. One film lasts for 3 hours. How much waste should be burned in connection with the whole film? Explain how you have solved this problem."

Oppgave 5:

En full avfallsdunk rommer ca. 16 kilo avfall. Det blir omgjort til 9 kilowattimer kWh strøm.

I tabellen nedenfor vises tre ulike mengder med avfall, de tilhørende mengder strøm som forbrenningen gir og tilhørende antall timer TV mht samme strømforbruk.

a) (Bruk tabellen) Hvor mange timer tv svarer til forbrenning av 4 kg avfall? Skriv resultatet i tabellen.

Kilo avfall	Strøm	Antal timer tv
16 kg	9 kwh	60
8 kg	4,5 kwh	30
4 kg	2,25 kwh	
2 kg		7,5
1 kg		

b) Fyll ut de resterende tomme feltene i tabellen.

c) En film du gjerne vil se varer 3 timer. Hvor mye avfall svarer i dette tilfellet til hele denne filmen? Forklar hvordan du løser dette problemet.

Table 1. Task presented to pupils at Returkraft by master's students

Some pupils have completed the table, though many of them with mistakes in the calculations of correspondence between kg of waste, electricity and TV hours. The questions related to the table were answered only by those who have calculated the quantities. Two main obstacles have been identified: the correspondence between units and quantities of a different nature for many of them and the interpretation of the text as well.

From master's students creating algebraic tasks

The beginning of the project was challenging for the students for many reasons. One of them was that the tradition in teacher education has been quite doctrinaire until recently, and as a consequence, the understanding of the approach of "teaching research based" became quite challenging. Another reason was the elaboration of the task emerging from the context of the enterprise. Teachers in general are used to following the textbook lesson after lesson, from the first page until the last one. The suggestion of asking for the elaboration of some tasks has been quite difficult for the majority of students. According to one of them

> "It is a challenge to design a good task. There are many different factors which must be evaluated in this process. I have, through this project, experienced that at the beginning I conceived the task as good and well elaborated, but when implemented the task proved to be something else in the next moment".

> "Unbelievable how much I have learned through this project. It is important that tasks are well elaborated and tested before their application. It is also important to see tasks from different perspectives. I have also learned how important is to formulate a good aim and reason for tasks to be developed. In this way, we can better support the pupils' learning".

From the evaluation of the project by one student we identify the gap which exists between her conceptions about skills and abilities to formulate tasks and the real possibilities to do it. We also perceive how the positioning of the student change when confronted with challenging activities. It becomes a positive position in connection with the learning opportunities which this project offers.

From the school teacher

He was very interested and engaged in the project from the beginning. One of his main concerns was to improve the motivation of his teenage pupils in doing mathematics, and also to get new ideas for developing concrete tasks related to a more meaningful context like the one involving the enterprise. At the evaluation meeting he suggested proposing the tasks to the pupils where the machines are operating. In the case of Returkraft it would be possible since the space is wide and well controlled.

From the pedagogue (Returkraft)

The aim of her professional activity is to develop educational projects related to the school system. In fact the enterprise's general administration has elaborated explicit policies to open the doors of the plant for pupils to visit and discuss issues related to productive use of waste. This material is collected in the region, transformed into electricity and warm water and returned to the same region. Concerning her participation in the MathEUS project she gave positive feedback and also asked to get the tasks included in the repertoire of activities of the pedagogical sector, to be used in connection with other schools as well. She appreciated particularly the inclusion of the university and the development of the "research exercises" by the master's students. Here she envisages possibilities for extending the project and organizing more meetings of the whole group of participants from the institutions involved.

Final comments

Implementing innovative ideas and actions in a traditional institutional structure such as the school is always a challenge and this project has been no different. However, elements which had not been envisaged at the beginning came to light during the developmental process. We pointed out some of these challenges: *For pupils*, to solve algebraic tasks outside of the context of the classroom, to solve tasks which were unfamiliar to them and to solve word problems with a new vocabulary in relation to the one used traditionally in the text books. For master's students, the challenge was to elaborate new algebraic tasks emerging from the industrial sector. When analysing the solutions of pupils' work, they realized how important it is to be precise in the formulation of a problem, and how important it is, not only to attune to pupils' ways of working, but also to try to amplify the scope of problems by providing explanations to situate them in the new context from where they emerge. Producing a research paper has been a major challenge for them as well. To focus on a specific area like algebra, review the literature, present data, explain, discuss and point out conclusions and pedagogical implications have been a great challenge. However, students also recognize the value of this project, particularly concerning the need to learn much more about task formulation. What drew our attention was the engagement of these master's students in all parts of the project and the good suggestions they provided in the final evaluation, for example, proposing the involvement of pupils in group discussions in mathematics lessons when solving tasks, as Banerjee and Subramanian (2012) suggested in their prospective teaching approach.

The continuum established between the micro situation of mathematics lessons focusing on algebraic tasks, as well as on word problems, and the macro perspective offered by interdisciplinary modes of working across borders of different areas of knowledge has been one of the highly appreciated aspects of this project.

One important component that touches today all societies and which emerged in the process of development of this project were the ecological awareness. This awareness does not emerge through words, oral recommendations or written documents. Instead, it is embedded into the nature of the problems elaborated by students and posed to pupils to be solved. Working on the formulation and on the solution of problems related to energy and ecology stimulates the identification of new problems and the search for new solutions particularly to societies in development. Pupils, teachers and future teachers are dealing with concrete problems of communities and larger societies. In this project, all participants have been touched by the correspondences between kilograms of waste, related to the production of electricity, and TV hours. All these calculations contribute to the construction of an ecologically aware mind.

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Looking at Science through the Lens of Diversity: Views of Indian Students and Teachers[1]

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The study examined middle school students' and science teachers' ideas on science and diversity parameters like religion. 1522 students from Mumbai completed a survey designed to elicit their perceptions of science, religion and learning experiences. Of these, more than a hundred students were interviewed and it was found that there was a demarcation between students' scientific and religious beliefs. Questionnaires were administered to 48 teachers and 11 teachers were interviewed who gave responses regarding their religious stance, classroom experiences and views on handling conflicts between science and religion. Results indicated that most teachers did not face problems with religious beliefs interfering with the subject matter and its transaction.

Introduction

Since independence, Science and Technology (S&T) have been central to developmental efforts in India, and this focus has a reflection in the Indian education scenario, where science is mandatory at the school level and students have a positive attitude to science (Chunawala & Ladage, 1998*)*. On the other hand, worldwide trends indicate that basic science courses seem to be losing out to other disciplines, particularly to professional courses, in attracting students. This has been a matter of concern especially in nations where there is a decline in numbers opting for basic science fields. A project "*Science Education for Diversity" (SED)*, funded by the European Commission under the FP7 programme, was initiated in six partner countries including India. The project aims to understand science education in the context of diversities arising due to differential factors like gender, culture, ethnicity, religion and habitat.

Science and diversity parameters in education

According to Lee and Luykx (2006) different aspects of diversity interact in complex ways to affect science attitudes and outcomes. Frost, Reiss and Frost (2005) advocate that science education orient itself towards the interests of minority groups and girls. Gender differences in attitudes to science, interest and achievement in science, choice of science subjects and careers in science have been extensively researched (Haste, 2004). Several studies on religion and science education have revealed the different views that science teachers and students have towards the theory of evolution (Dagher & BouJaoude, 1997; Kose, 2010). In India individual identity is a result of a complex network between caste, class, religion, language, region, ethnicity and gender. This diversity is not adequately addressed by the education system, which considers students to be homogeneous, has science as a compulsory subject at school, emphasises a uniform curriculum and has central development and dissemination of textbooks (Chunawala & Natarajan, 2012).

Science Education and Religion: The Two Pole Contradictions

Most science curricula depict science as objective, non-negotiable, culture-free and value-free (Schwedes, 2008). Research in science education has uncovered that students hold alternative conceptions of scientific ideas that arise from their personal experiences and backgrounds (Lawson & Thompson, 1988). Such conceptions are considered to be potential obstacles in the path of learning. According to Reiss (2004), scientific understanding and what conceptions individuals in a society have regarding the world differ on account of their gender, religious beliefs, age as well as ethnicity. Hermann (2012) in a study on high school students found that when scientific concepts conflict with religious views, there tends to be less belief in the former. Studies on college students' perceptions of evolutionary theory have found these to be influenced by religious beliefs, world-views or social expectations (Dagher and Boujaoude, 1997, 2005, Sinclair and Pendarvis, 1997, Scheitle, 2011).

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A study by Kose (2010) exploring the attitudes held by Turkish secondary school students and teachers revealed that religious beliefs, teachers' attitude and teaching, all played a crucial role in rejection of theory of evolution by students. A study by Mansour (2008) on 75 Egyptian science teachers found that their pedagogical practices regarding scientific issues related to religion were affected by their religious beliefs. According to Singh (1999), the principles behind science and religion and their inter-relationships are poorly understood by various sections of the Indian society, who as a result experience a philosophical conflict.

In the Indian context, we found limited studies that addressed diversity and science education. We feel that the experiences students and teachers bring to the learning environment and how these interact with the prescribed science curriculum need to be studied. There is a need to focus not only on students' and teachers' understanding of science, but also on the affective domain of feelings and opinions attached to science learning.

Methodology of the Study

Questionnaires were administered and interviews conducted with teachers and students in Mumbai to uncover their perceptions of the role of diversities in science classrooms. The questionnaires were developed in collaboration with all the partner countries of the SED project. The student questionnaires addressed aspects of diversity, attitude towards science as a subject and experiences in science learning. Some students were further probed through interviews. The questionnaires and interviews conducted with teachers addressed their science pedagogical practices and classroom experiences in relation to markers of diversity such as gender, language and religion.

Tool	Number of schools from which sample is taken	Sample Size		
		Female	Male	Total
Student's Questionnaire	5	672	850	1522
Students Interview Schedule	8	55	53	108
Teacher's Questionnaire	9	41	7	48
Teacher's Interview Schedule	4	10	1	11

Table 1. Description of sample

Findings

Students and religion

When asked to state their religion, only 6% of students chose not to answer. This indicates that there is no stigma associated with revealing religious identity. The students represented all the major religions of India (Hinduism, Islam, Christianity, Sikhism, Buddhism and Jainism). Regarding religious practice, only 3% said that they never visit places of worship, while 52% stated that they visit places of worship every week, with boys (56%) outnumbering girls (46%). However this need not imply that boys are more religious, since other factors could play a part such as greater mobility and restricted access to religious spaces. A majority of the students, 75% stated that they prayed at least once or more than once a day. When students were asked what they would like to reveal about themselves to a new person, 26% of the students considered religion not important enough to be divulged, whereas 43% considered it very important and 31% thought it was of little importance.

Origin of life: Students' multiple perceptions

The student sample was probed about the origin of life by the question “where do we come from?”. They had to state which of the three statements they agreed most with. The first option which supports evolutionary theory (*life on earth including human life has evolved over millions of years and some creatures like dinosaurs became extinct long before humans evolved*) was accepted by 42% students with some gender based variations in terms of the boys outnumbering (46%) the girls (37%). However, the other two options- *most life on earth evolved over millions of years but God created human life* (34%) *and God created all forms of life on earth at the same time, about 10,000 years ago* (24%) did not show much gender differences. More students accepted that God was responsible for either human or all forms of life, and the view that most life evolved but God created human life was favoured more.

Students' ideas about the beliefs of their families and teachers about origin of life

When asked about their families' beliefs, most students (45%) responded that they think their families would support the option that God is the creator of human life and only 33% felt that their families would support the evolutionary explanation. This pattern was the same for girls and boys.

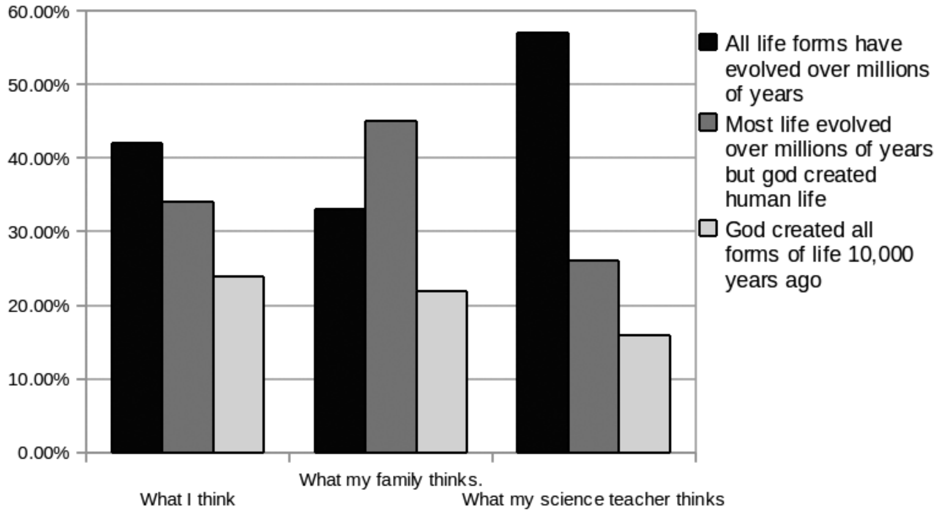

Figure 1. Student's ideas on self, family and science teachers' stance about origin of life

A striking feature emerged when these students were asked to comment on the beliefs of their science teachers. More than half (58%) of the students stated that their science teachers would support the evolutionary explanation of the origin of life. This suggests that students can demarcate between ideas that are scientific with those that are not and are aware of who supports what. It is therefore essential to analyse the experiences of students in dealing with their personal systems, family beliefs and scientific explanations. There may be instances of conflicts, whether internal or external, which may go unnoticed in a class session.

In-depth interviews conducted with students sought to analyse their responses to the question: *Suppose you had a friend who said that their religious holy book explained the beginning of the earth and of human life very differently from what scientists said, and so your friend thought the scientists were wrong. What would you say to your friend?*

Around 63% of students felt that only the scientific argument is valid because it is based on evidence while religion is based on belief not evidence. Around 27% of the students acknowledged the arguments of both science as well as religion and gave equal weight to both. Less than 5% of students acknowledged both science and religion, while recognizing the difference on the basis of argument in both cases, and 3% considered religious argument to be paramount. Only 3% of the students said they did not know or could not answer. The responses of the students to the above question have been categorized in Table 2.

Students' responses to how they would counsel a friend who thought scientists were wrong?	
Reconciliation - but science is more valid	"You can believe both also, because holy book is your religion... every one follows in your caste... in your religion... so you can follow that. But scientist (sic) thinking is more correct because they study about all this in the past... and present they are studying. So I think scientist would be better" **(Girl)** God is a belief that we have... we can't tell hundred percent that yes God has made it... ...yes in religious books it's written... but scientists have a scientific reason they have researched" **(Girl)**
Reconciliation	"Both are correct as they are free to give ideas about the starting of life... of earth... of humans" **(Boy)** "Scientists tell the evolution of earth in scientific ways, but the religious books tell the mythological way of how earth has evolved. We can say both are right, we should not hurt the religious sentiments, it will lead to quarrel" **(Girl)** "If their holy book is explaining it then I would not insult it but I would like to explain in a friendly way. He/she should refer to some Geographical book which will explain it in a better way according to science. So she should not feel I am making her holy book wrong. She should feel that her friend is at her side also and not on scientist side, so she can understand it better" **(Girl)**

Students' responses to how they would counsel a friend who thought scientists were wrong?	
Religion is valid	*"Sometimes, they can be wrong because scientists are not God"* ***(Boy)*** "Some scientists may be wrong, but the (holy) books are right" **(Boy)**
Science is valid	"I will say scientists are right. This is the generation of science. It is better to be with the scientists, to accept truth and know more" **(Girl)** "Scientists are right because they have done research" **(Boy)**
Unsure	"I will tell no one is sure whether the scientist are right or the holy books" **(Boy)** "I will not tell anything, as we also don't know the truth" **(Boy)**

Table 2. Categorization of students' responses to conflict between science and religion

Teachers' experiences of conflict between science and religion

Around 73% of teachers said that they were believers, but not active believers, while nearly a fourth of the teachers (24%) said that they were active followers of their religion. Only 2% of teachers said that they were non-believers. During the course of teaching science there is a possibility that certain aspects taught in science (e.g. evolution) may contradict religious ideas, and may cause the student/ teacher to experience conflict. Teachers were asked whether they had experiences of any student/s stating that the science lesson conflicts with his/her religious beliefs. A small percentage of teachers (13%) said that they had such experiences. All the teachers, regardless of their experiences, were probed on how satisfactory they felt were each of the given statements regarding such conflicts in the classroom. The results in Table 3 indicate that teachers are satisfied or very satisfied with the given statements. The first two statements emphasize scientific evidence, the third and fourth identify the compartmentalization of science and religion and the fifth gives the choice to individuals to follow science or religion as they are both seen as two plausible explanations.

Statements	Very satisfactory	Satisfactory	Unsatisfactory
1. In science we look for evidence and scientific evidence supports what I said in the lesson	16 (38%)	23 (55%)	3 (7%)
2. Religion is based on faith and tradition and people may take lessons on how to live from these but this is separate from scientific evidence which looks for facts and tests theories unrelated to religious beliefs	23 (54%)	15 (35%)	5 (12%)
3. Many scientists hold religious beliefs but see no conflict between their religion and their science because they see them as different parts of their life.	19 (43%)	22 (50%)	3 (7%)
4. Many scientists have religious beliefs and the wonders they discover about the world through their science makes them appreciate religious ideas but they do not mix scientific and religious explanations.	21 (48%)	22 (50%)	1 (2%)
5. Religion and science are two ways of explaining – everyone must make their own choice.	18 (41%)	18 (41%)	8 (18%)

Table 3. Teachers' responses to handling conflicts between science and religion

During the interviews, the teachers were asked if they had encountered any challenges in teaching science to students due to the students' different religious belief systems. Of the ten teachers interviewed only three reported that they had faced such challenges, and their responses were; "Many times it happens but I always stick to science", "I will explain, not get angry", and "I will explain to him/her in a scientific way & ask them to choose, but I will not pressurize them, they can choose to go on scientific way or religious way, but I will definitely tell the reason". The other teachers were asked to hypothesise such a situation arising in their classes and respond. Three teachers said that they would respond in terms of affirming scientific evidence and facts, two teachers said they would state that science is based on theory and this is what scientific people accept and believe. One teacher recognised the possibility of a conflict between religion and science and used this as a basis for getting students to acknowledge existence of many points of view. One teacher denied that there can be religious diversity issues in relation to science.

Teachers learning from diversity in classroom

In response to whether the teachers themselves had learned from the experience of teaching multi-cultural and diverse classrooms, 3 teachers stated that they had never reflected on such experiences. A teacher said that she had learned the importance of knowing about different views and of teaching tolerance: *"Everyday I learn tolerance, how to be more patient... you learn from different individuals".* Another teacher through experience had learned the importance of being sensitive to students' different perspectives. One teacher felt that it was best to ignore diversities in the classroom: *"In science classroom we do not discuss about religion, for me they all are same, they are children - not boys or girls".* Another teacher preferred to support science in the face of diversity: *"I respond by giving scientific reasons and clearing doubts. Religion and castes we only created... so... by giving correct reasons and explanation... It's up to them to believe it or not".*

In another context where 7 teachers were interviewed, one of the teachers when asked about teaching diverse students, responded that for teaching the theory of evolution, he often established linkages with culture by using a specific mythological interpretation – the *Dashavatars* (term for the ten different incarnations of the Hindu God Vishnu). This example was used with students in the Standards 9-10 where heredity and evolution is introduced. When this teacher was asked to comment on how students from other religions would respond to such an interpretation pertaining to one religion, the teacher responded that as he had no knowledge about the religious beliefs of other religions, he would teach evolution to such students using the scientific explanation.

Discussion

Many studies have concluded that in comparison to men, women are more religious (Argyle & Beit-Hallahmi, 1975; Stark, 2002). But in this study more boys reported visiting places of worship frequently in comparison to girls. However, this does not suggest that boys were more religious. In a country like India, there is an amalgamation of many religions, each with their own set of restrictions, as well as other cultural norms, which may hamper mobility of females. Conversely, many studies (Cornwall, 1989; Feltey & Poloma, 1991) have also concluded that the stereotypic imaging of women as being more religious is misleading. This has also been reflected in the finding of this study regarding frequency of praying which showed little dependence on gender difference.

In our study, over half the students disregarded the scientific theory of origin of life and accepted that God created human life, or that God created all forms of life. This finding is aligned with the study of Dagher & Boujaoude (2005). Most students also responded that their families would believe that life evolved over millions of years but God created human life, or that God created all life. The reconciliation of religion and science demonstrated by students in our study are similar to the findings of a study conducted by the British Council and Ipsos MORI (2009). The latter surveyed over ten thousand adults across ten countries worldwide. From all the countries that were surveyed, adults in India showed the highest level of agreement to the statement that '*it is possible to believe in a God and still hold the view that life on Earth, including human life, evolved over a time as a result of natural selection*'. Though this study was conducted with adults, it is interesting to note the similarities in views expressed by the middle school students in our study on the origin of life.

An interesting finding in our study was that students felt that their parents would believe that God created human life more often than they themselves did. A study by Woods and Scharmann (2001) on the attitude of high school students towards evolution concluded that religious factors were the greatest influence on students' attitudes to evolution, followed by factors such as personal relationships with parents, teachers and friends, and the extent to which students can comprehend the knowledge presented to them regarding the topic of evolution in terms of the evidences provided.

In our study, the students had probably very little or no exposure to the topic of evolution as the topic gets introduced in later school years. In this regard, while many students regarded God as the supreme creator of life, a striking feature that emerged was that, when the students were asked to comment on the beliefs of their science teachers, more than half of them said that the teachers would consider evolutionary explanation for the origin and variety of life, and not God. Thus students could clearly differentiate between the beliefs of their families and teachers with the former highly influenced by religion and latter more by scientific views.

Students when faced with a situation where a friend is rejecting the scientific viewpoint due to religious reasons responded with different options. The largest responses were "only the scientific argument is valid as it is based on evidence," followed by "acknowledging both the arguments from science and religion". Most students gave interesting quotes in the interview which had elements of (a) reconciliation of science and religion, (b) validity of science, (c) validity of religion, and (d) a reconciliatory approach but inclined towards scientific argument.

Similarly, teachers also had mixed opinions on handling challenges to science on the basis of religion. A study on the religiosity of professors has shown that while professors are religious, they are secular and believe that the boundaries of religion and science should not be crossed (Gross & Solon, 2009). In the current study, teachers either emphasize science over other evidence, compartmentalize science and religion or overlook the conflicts that arise or ignore these conflicts. It is crucial for teachers to be aware of students' beliefs. The deliberate avoidance of religion by textbooks and teachers creates a situation where the topic is evaded and students are left on their own to find a way to resolve the contradictions. They then either hold on to their beliefs, reject science or experience conflicts.

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Beating the Language Barrier in Science Education: In-Service Educators' Coping With Slow Learners in Mauritius

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This study describes how in-service teachers in the pre-vocational sector in Mauritius adopted specific strategies ***to overcome the language barrier in the learning of science*** *(Van Driel, Verloop & de Vos, 1998). Students of form III were taught few basic ideas related to "Earth & Space" through the use of role play and ICT. The concepts chosen for this study were 'occurrence of day and night', 'relative positions and motions of the Earth, the Moon and the Sun' and 'main constituents of our solar system'. Classroom observations, focus group discussions with students, interviews with educators and post-test for students showed that role play and ICT can potentially overcome the language barrier in the learning of science at pre-vocational level. Findings reveal that during explanation, reading and writing should be kept to a minimum while use of Mother Tongue (Kreol language) and hands-on activities with oral interactions must be encouraged during lessons conducted in pre-vocational schools.*

Introduction

The pre-vocational stream

Science education is an essential component of the Mauritian curriculum, including the revised pre-vocational curriculum introduced in 2001. However, teaching and learning of science is very closely linked to literacy. It means scientific literacy would not develop much if there is no proper language acquisition. In spite of the national urges and efforts made to promote scientific inquiry and science education in the Mauritian context, a very slow progress is reported. A report by the Mauritius Research Council (2004) regarding scientific literacy among students in Mauritius, states that we are very much lagging behind our international counterparts. The report highlights that classroom based resources are inadequate, especially for science instruction. Teacher motivation is satisfactory but low motivation level of students remains a major hindrance. In an attempt to motivate students, the government has come up with several schemes such as free education at pre-primary, primary and secondary levels i.e., no tuition fees are charged, free transport for students and social aids for needy students. Further efforts include compulsory education till the age of 16 so that dropouts can be minimised. Still we find that learners are not attract to science. This situation is worse among pre-vocational learners. These are students joining the sector are those who have failed after a second attempt, in most of the academic subjects (English, French, Mathematics, History & Geography, Ancestral language and Science). Their continuous failure is attributed to lack of interest, poor parents who are not able to provide basic amenities and care, issues related to broken families, poor educational background of parents, busy or separated parents, learners not having enough competencies to climb to next level in the curriculum, tight assessment schemes not catering for low ability students and so on (Ministry of Education and Human Resources (MoEHR), 2011).

The national curriculum for the pre-vocational stream caters for areas such as basic skills in numeracy and literacy, life skills and communication skills (English, French and Creole), Basic Science and trade oriented subjects. In this stream students learn basic ideas related to trade skills, life skills, numeracy and literacy and communication skills. Poor literacy skills further accentuates learning difficulties in areas including science.

Out of the roughly 25000 students who participate in the Certificate of Primary Education (CPE) Examination, about 35% are not able to pass and move to secondary schools (Mauritius Examinations Syndicate, 2010). A second attempt is not promising either. These learners then join the prevocational stream alongside a mainstream secondary class (Auckloo, 2011). They follow a specific tailored programme with teachers specially trained to work in these schools, with focus on ways to address learning difficulties and remedial education.

Rationale of this study

It is believed that most of the social ills are the products of illiteracy, which are intertwined with problems of poverty, delinquency, drug dependence, HIV AIDS, prostitution, teen age pregnancy, and crime. If we aspire to live in a better society, everything possible should be done to reverse the escalation of problems related to illiteracy and poverty which is also related to the problem of dropouts. One of the ways to achieve it is through literacy among the low ability or deprived students. Given that traditional methods have failed to motivate most of these learners, innovations need to be trialled. So this study aims to trial one innovation which is minimisation of the language issue in the learning of science through role play and ICT.

Through this study the researchers and educators are finding out ways to engage low ability learners in meaningful learning experiences such as role play and ICT. It is believed that role play is one of the methods that can engage learners into meaningful classroom transactions (Cyparsade, Chummun, Carooppunnen and Moheeput, 2011; Cyparsade, Moheeput and Carooppunnen, 2009; McSharry and Jones, 2000). It will be an opportunity for educators to learn about new techniques, up to date resources including ICT and interactive pedagogy and also how to present information in a variety of formats (Steele, 2004).

The medium of instruction in the prevocational sector has for long time been restricted to English and French languages, although teachers use the mother tongue from time to time. Research and latest development in the Mauritian prevocational sector has prominently called for increasing use of the mother tongue or the Kreol language (MoEHR, 2011). In line with the current and recent reform that has started in this sector since 2011 (MoEHR, 2011), increasing importance is being given to the language component to facilitate learning in other areas through the mother tongue. It is also being envisaged to assess the learning of science in Kreol language just to avoid the language barrier and carry out a reliable assessment. The present research is thus in line with a merger between approaches that includes role play, ICT as well as the use of mother tongue.

Aims of the study

The aim of this study is to support the educators' use of role play and ICT in pre-vocational schools in Mauritius for the teaching and learning of basic science and to reduce the language barrier among low ability learners.

Research questions

1. How far can role play and ICT support learning of basic science at pre-vocational level?
2. What are the constraints facing the implementation of role play and ICT in the teaching of basic science to low ability learners through English usage?
3. To what extent the teaching and learning of concepts related to Earth and Space can be achieved through role play, ICT and Kreol?

Literature review

What is being offered to students in pre-vocational education sector

For the first time there has been a National Curriculum Framework Secondary (NCF), in 2009, for Pre-vocational Education in Mauritius. According to the NCF (2009), pre-vocational education must, among others:

> Enable the holistic development of each individual learner, foster the ability for critical thinking, creativity and self-expression in learners, prepare learners for lifelong learning, develop functional literacy and numeracy that will serve as the basis for vocational training, apprenticeship or further education, develop problem solving skills (NCF, 2009)

All these objectives will be translated to our students through four domains, which are **Communication Skills, Numeracy and Problem-Solving Skills, Life Skills and Livelihood and Trade Skills** (NCF, 2009). In line with this NCF, Numeracy and Problem Solving Skills calls for the use of ICT as a support for learning.

Work being done in pre-voc sector currently

Educators in the pre-vocational sector are performing according to what is stipulated in students' workbooks and with the aid of teachers' guides provided to them. Many of these educators do possess a specific qualification needed for teaching of low ability students (75%) and only a few of them have not undergone specific training in the field of special educational needs i.e., remedial education. All of them possess a School Certificate and many of them have a Higher School Certificate (60%). Around 11% of these educators possess a Diploma in pre-vocational education and around 9% of them have a Degree (MoESR, 2003). Though teachers have been trained, there is inadequate provision of good quality teaching – learning experiences to learners. This is making the teaching and learning process more difficult in the pre-vocational sector, where more effort should have been put to help the low ability students. Another drawback in this sector is the severe lack of resources which is the cause of poor response and retention from these students.

What was missing in pre-voc schools so far?

> It has been widely recognised that periodic in-service training is essential in order to compensate for the shortcomings in or lack of training of those teachers who are in the field along with keeping them refreshed about recent pedagogical developments. (Agarkar, 2005, pp.161-162)

In line with the above statement the current study has attempted to meet the shortcomings of the sector through concerted efforts. These include training and resources provided to teachers, resources provided to students, funding and also assessment of learning. Even the textbooks for the pre-vocational sector have been revised so that appropriate materials are provided to learners. Capacity building for inspectors, heads of institutions, educators (including temporary ones) have been conducted so that they can drive the implementation of the new curriculum. These were unfortunately less prominent until recent developments.

Use of role play in science lessons

The reason why role-play can help to make science relevant to many children, is that it is based upon 'play' (Munirah, 2006; McSharry & Jones, 2000). If the teacher steps into his classrooms with the same kind of planning, usual strategies, almost same questions, unchanging resources and evaluation techniques, then it may become very boring for learners, especially if they are low ability ones (Cyparsade, Chummun, Carooppunnen & Moheeput, 2011; Nickerson, 2009; Sukhoo-Busawon, 2008). In this study, role play, ICT and Kreol language have been chosen as these have not been implemented so far at the pre-vocational level in the teaching and learning of science in Mauritius. Actually, learners need to internalise certain abstract concepts through the engagement of more than one sense at a time, through role play and other activities (Sharma, 2006).

Use of ICT in science lessons

The use of ICT in Mauritian classrooms has been introduced since late 1990s (Isaacs, 2007). Several initiatives have been taken by the Ministry of Education & Human Resources, the Mauritius Institute of Education (MIE) and other stakeholders.

> Mauritius has attempted to promote ICTs in schools since the late 1990s which is reflected in its national ICT policy, a segment of which is dedicated to education. (Isaacs, 2007, p.2)

The MIE has introduced ICT modules in all teacher education programmes as a subject and also as an important support for the teaching and learning process. All pre-service and in-service teachers are encouraged to use ICT in their planning, teaching and assessing tasks.

> The introduction of ICT in the school curriculum worldwide has brought a drastic change in the way concepts are taught. (Ramma, Dindyal, Kah Chye & Cyparsade, 2006, p.717)

Use of ICT in science lessons in creating and maintaining interest of learners especially through animations and graphics, activating mental processes of learners.

Use of mother tongue in science lessons

In Mauritius most learners' mother tongue is Kreol. However, they need to study most subjects in English and only one or two subjects are in French. In this situation there is lots of confusion in the minds of low ability learners. They are faced with two barriers in their learning process, the content and the English/French language. In this situation students of low abilities should be taught using the mother tongue to at least remove one barrier to learning. For so long, there was debate about whether Kreol should be used in formal instruction. The NCF 2009 has made provision for the use of Kreol in instruction especially with low ability students (MoEHR, 2003).

Motivation of low ability learners

Educators should be aware of how to motivate learners, once motivation is established (intrinsic or extrinsic), learning is easier to occur.

> When people are motivated, they intend to accomplish something … students' motivation plays a crucial role in science learning. (Sevinç, Özmen & Yiğit, 2011, pp.218-232)

Engaging educators to cope with the language barrier

Though educators in the pre-vocational sector are qualified, they need additional support in schools to implement the new NCF and innovative strategies. Several training workshops were organised to explain to educators what is there in the curriculum for understanding nature, how to teach them through meaningful activities and projects, even use of innovations and ICT has been demonstrated.

Methodology

Sample

The group on which the research focused is prevocational teachers in Mauritius. A convenient sample (Cohen et al, 2002) of ten educators participated in this study. The teachers were of both genders, holding appropriate pedagogical qualifications to teach pre-vocational students and having several years of teaching experience in the pre-voc sector. These educators were chosen as they were willing to take initiatives and few who are in the panel of curriculum writers for pre-vocational science.

Modality of the planning and intervention

"Basic Astronomy" was selected as it is directly related to students' daily life and could be illustrated with animations and graphics. The concepts that students learn at form III level in pre-voc stream are: Our Solar system, Planets and other bodies, Relative motions of Sun, Earth and Moon, Occurrence of eclipses and Occurrence of day and night on Earth. Concepts such as our solar system, planets and other bodies in our solar system, relative motions of sun, earth and moon and the occurrence of day and night on the earth, were chosen. A PowerPoint Presentation was prepared by the researchers. The PowerPoint included hyperlinks to Encarta Encyclopaedia, colourful photographs and artists' impressions related to these concepts, interactive simulations and video files showing celestial bodies and their motions. Along with ICT, it was planned to use role play to reinforce the idea of motion of the moon around the earth, simultaneous motion of the moon around the earth and motion of the earth around the sun, motion of planetary bodies around the sun, and also the occurrence of day and night on the earth.

All these chosen topics were taught by the educators, in their classes in two periods of one and a half hour each. Educators started the session by written pre-test with questions: what is a planet, what is the shape of the Earth, how many planets are there in our Solar System, name the planets found in our Solar System, what is a Moon, what causes day and night on earth, etc.

The pre-test was in English and textual information was sought through a worksheet. When the scripts were collected and analysed, it was found that most students could answer even the simple questions. They did not understand the questions asked. They were then asked the same questions orally by the educators and most of the time it was answered in Kreol (L1). It was found that students were able to communicate more fluently in the L1 and then answer some of the questions set in the worksheet. It was also found that once L1 was used, students were ready to talk freely on the topic, they even asked questions to the educators conducting the lesson. Gradually they became much enthusiastic and the lesson became interactive.

The next step was to use the PowerPoint Presentation including animations. Role play was used to supplement the explanation. This teaching session lasted about 60 minutes. In the following lesson, presentation continued for one hour till all concepts identified by the researcher were taught. This lesson ended with the administration of the post-test by the educators.

Tools used in this study

- Pre-test; written test with simple questions on basic astronomy with short answers
- Post-test on same topics, testing how far the educators' interventions facilitated understanding
- Second post-test on the same topics, using a worksheet with lots of visuals where students had to label several diagrams and give very short answers; this was used to test the difficulty with the English language
- Interview of educators and a pedagogical inspector to find out their perception on the study
- Focussed group discussion (FGD) among students to find out their perception on the use of ICT, role play and especially Kreol

Role play

Ideas chosen for role play were Earth – Moon system, Sun – Earth – Moon system, Solar System, Occurrence of day and night on Earth. For the Earth – Moon system two students of different heights and body size were involved. The small one represented the moon and rotated around the larger body representing the earth. For the Sun - Earth – Moon system three students of different height and body size were involved. The small one represented the Moon and rotated around the larger body representing the Earth; while the Earth was moving around the Sun and spinning slowly at the same time. For the solar system a group leader was assigned, s/he was asked to work along with other ten members of the group to perform a role play to show how the planets move around the Sun. They had to prepare word cards on which the Sun, Moon or the name of a planet was written. While doing the role play they were supposed to express which celestial body each one represented. E.g., “Hello friends, I am the Sun; all the 8 planets rotate around me. I stay in one fixed position”. The modelling of occurrence of day and night was also demonstrated using a role play. Students were taught this concept using a globe and light from projector representing sunlight.

After viewing this model, students were asked to reflect in groups about how they can use role play to demonstrate the occurrence of day and night on the earth. Students were able to manage the role play using a torch in front of a student, who would spin slowly. When the light fell on the face of the student, s/he would say “day time!” and when there was no light falling on the face of the student s/he would say “night time!” and continue to spin.

Findings of the study

Pre-test

During pre-test learners were not very enthusiastic as they could not decipher the questions. The classroom teacher tried to explain the questions in Kreol and asked them to write answers in Kreol if they cannot manage with English. This was yet another evidence of the language barrier in the learning of science. Many students could not imagine any other planet’s name apart from Mars. It was astonishing to find out that very few considered Earth itself to be a planet. Many worksheets were returned nearly blank or with answers to only the first few questions out of 13. Most important misconceptions demonstrated by students in the pre-test: A star is a planet, the Sun is a planet, Mars is a planet (only one), planets are small and far from that Earth, Earth is not considered to be a planet, the moon is a planet, etc. These ideas have already been taught at primary level in “Earth & Environment”, but have not been grasped by the students. This situation thus informs us about prior knowledge of learners as well as their predisposition to grasp and understand additional concepts in their curriculum.

Response of students to the PowerPoint Presentation

During the interview, students said that normally they use chart paper, wax crayons, scissors, glue, soap and posters that teachers make or ask students to make. They do not even get access to Biology, Chemistry or Physics labs. In only one of the ten schools, students stated that they had been to the labs on few occasions and they liked so much the activities and demonstrations performed. Before the presentation, the objectives and content of the lesson were read and explained so that students know what to expect in the presentation. Students were very enthusiastic as the lesson unfolded through the slides and so on. They asked what is “etoile filante” i.e., a shooting star etc. All questions were answered by the researchers and educators.

Use of low cost 3D model of our solar system

Along with the PowerPoint presentation, students were shown a low cost 3D model of our solar system, how the planets are arranged around the Sun, their relative distances and sizes were exposed. Students could interact with the model and rotate the planets about a central axis. Some students expressed that they would create a model, given that easily available materials have been used (Waldron, 1998; Cyparsade, 2006; Wardle, 2009). Another marking point in the explanation was the Kreol version of the mnemonic, that is used to recall the positions of planets from the Sun. They were initially given the English version but it did not attract much attention.

***M*y *V*ery *E*nergetic *M*other *J*ust *S*erved *U*s *N*oodles**

Mercury Ve*nu*s Earth Mars Jupiter Saturn Uranus Neptune

The Kreol version that the researcher has devised is:

Mo Voisine Envie Met Juste So Uniforme Nef

Which means:

My neighbour wishes to wear only her new uniform

This sentence is actually related very much to school life of youngsters.

When this sentence was given on the slide, most students took notebooks to write it. In fact, during the following session, most students could recall the names of the planets in the correct order starting from the sun. Another hint was given: the last 3 planets' names start with the letters S - U – N related to the word Sun. This would also help students to recall the planets in the correct order from the sun. It should be noted that the intention was not to make learners rote learn, but to use the sentences and tips as support till the concepts are understood, the sentence is not needed.

Post-test

The first post-test was conducted through the same worksheet used for pre-test. It was planned to verify how far the researchers' and educators' interventions had made the students grasp the basics of astronomy. It was very surprising to see that these students could not answer simple questions on what was taught. The first post-test was intentionally structured textually so that it may be established whether reading poses a difficulty for these pre-vocational students. Students could barely read and decipher the questions and write answers to these simple questions. To be able to assess the understanding of science content by these learners, without going through the difficulties of English language, a second post-test was devised.

Second post-test

Only large diagrams related to the topics studied were provided in the worksheets. Students were expected to discuss in groups and then answer the questions set by labelling the diagrams and adding a few words to describe what is being observed. The second post-test gave a clue to the difficulties of the pre-vocational learners. It may be that if the assessments are conducted orally and in Kreol, most students would pass in science tests. In the NCF 2009, it has been proposed to assess students using innovative strategies such as through projects, making of artefacts, presentations and also oral tests involving Kreol.

Educators' views on the use of Kreol, role play and ICT

Educators' views were also collected through interviews, they commended the remarkable enthusiasm of students when these innovations were brought to their classrooms. They are all for the use of Kreol, role play and ICT, as long as meaningful learning takes place. They mentioned that they have benefitted from the in-house training on the use of role play, ICT and Kreol in their lessons (Bender, 2005) and that further training and initiatives are needed.

Students' views on the use of Kreol, role play and ICT

Students' views were collected through a focus group discussion, after the two working sessions and after filling in the two worksheets in the post-test. It was found that students are very much interested with the content of 'basic astronomy' as it is directly related to their everyday life. In fact the learners got so much involved in the discussions and they also asked very pertinent questions. Students expressed that innovations brought to them have been beneficial as they can now understand many things which were difficult before. They are also of the opinion that use of Kreol is very important for understanding of ideas in everyday life.

Conclusion

Through the methodology employed, resources prepared and the strategies deployed by the researchers and educators, it has been established that role play coupled with ICT usage can indeed stimulate the learning of basic science/astronomy by pre-vocational learners. This is also made more accessible to learners through the use of the mother tongue which thus further engages learners in meaningful interactions. Both the educators and the learners engaged in the activities which they found meaningful and appropriate. Prominent constraints included shyness of learners, language barriers and indiscipline, but these issues were counteracted by creating an appealing learning environment through innovations, that are suitable for low ability learners. So we can say that ICT, role play and the use of Kreol are very appropriate for the teaching and learning of basic astronomy by pre-vocational learners.

Limitations of the study

The sample was limited to ten educators and so it is difficult for us to say whether the influence of role play, ICT and Kreol language would significantly inform the teaching and learning of science. Only ten educators benefitted from this in-house training in Mauritius. It would have been very conclusive if a larger sample were used. This could include further research in the use of Kreol, role play and ICT in other topics in science, across different levels of the pre-vocational sector. The data analysis is only qualitative in nature, and it was not the intention to analyse the marks in detail. A longer term research would substantially inform the other dimensions of the study and theory as well as researchers and practitioners in the area.

Recommendations

The use of L1 is a must during activities as there is already a learning barrier which is the content. At least one barrier (language) can be removed or alleviated for appropriate learning to take place in science. Resources used should be innovative to attract and maintain the attention of these low ability students. Lots of interactions should be envisaged, ample questions should be asked and learners should be encouraged to ask questions to clarify any doubt they have in mind. Other aspects to bear in mind with pre-vocational learners is the assessment could be partly in Kreol to help learners. It is recommended to use tools such as oral tests, demonstration of learning by drawing, labeling diagrams, oral explanations of phenomena and even problem solving by drawings, sketches, annotated diagrams, project works and oral presentations, without much language pressure. This study was driven by teacher educators, however, educators too should be able to engage in classroom research and share their good practices (Agarkar, 2005).

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Addressing Understanding of Nature of Science: A Case Study of Pre- Service Elementary Teachers

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This paper explores how nature of science is addressed in the elementary education curriculum of the University of Delhi. Further, in this empirical study the pre service elementary teachers' views were identified about 'nature of science'. Also, their understanding about nature of science was developed through six different 'Learning about Science' (LAS) teaching modules. LASTM were designed using controversies in science (like genetically modified food, bio – fuels, The Silent Valley, example from history of science (for instance the structure of atom) and biographies of scientists. These teaching modules were tried in three different colleges of Delhi over the period of one year. As a result of this students' views changed considerably but in varying manner as some ideas are either more deeply entrenched or not sufficiently challenged through modules.

Nature of Science

The concept of 'the nature of science' dates back to more than one hundred years. In 1907, it was first discussed and promoted in the Central Association of Science and Mathematics Teachers. This association advocated an understanding of the nature of science an important goal for all students studying science. The popularity of 'Nature of Science' has been growing. In India, the term 'Nature of Science' now appears in the objectives of teaching science (NCERT, position paper on Science Education)

Generally science is viewed as 'objective', which means an unbiased and impartial observer looking for explanations of physical phenomena. The observer also believed that explanations can be found out in an external reality. The values involved in 'investigations' are detachment, honesty and impartiality. In this school of thought, often labelled as 'positivism'; there is implicit distinction between observers and observed or subject and object.

On the contrary, Thomas Kuhn (1970) advocated that the *scientific community is, essentially, a closed society operating for the most part in the realm of "normal science"(1970)*. Thus necessity of a prior conceptual framework, even to make sense of observations, gained importance. He challenged the assumption of science based on individual enterprise, empirical evidence, rational argument, objectivity and value neutrality. Rather he proposed that science proceeds through the socially embedded activities of its practitioners, with scientific knowledge developing through cyclic periods of consensus and dissensus among the members of the community (Chalmers 1976). Thus, science was seen as a complex, value – laden enterprise, subject to the range of human social behaviours including ambition, care, jealousy, and friendship. He gave importance to looking at a community of scientists, with a portrayal of their lives, their social and professional interaction and the psychological drives that underpin their activities (Alters 1997). His work challenged the positivism school of thought. Till today there is no single accepted definition of Nature of science.

Nature of science and school education

The different philosophical positions brought changes in the way school science is viewed. There have been major shifts in emphases and the ways in which science educators have conceptualized nature of science. In the 1960s, the sputnik acted as a catalyst for nature of science being viewed primarily as science process skills, such as observing, hypothesizing, inferring, interpreting data and designing experiments. A special focus was given to observation and reliance on inductive inferences as part of teaching science. It was believed that observations lead to scientific knowledge and thus a good observer was taken to be '*objective*' and '*theory free*'. In school students were expected to spend more time in the laboratory making observations, even if they were not necessarily constructing knowledge. Objective observations coupled with inductive reasoning gave a greater focus to the so called "scientific method".

The shift from a positivist stand, which held that scientists just observed what existed in nature and therefore students too needed to behave like scientists (Driver et al 1996), to a constructivist position made educationists too shift from 'a scientist centered' to 'student centered' view of school science. The humanistic perspective in science was promoted by Aikenhead (1987) and intended '*to prepare students (future citizens) to critically and rationally assess science and technology'.* Since science is not seen as happening in isolated laboratories but in a social and cultural context, the influence of science and technology on society and vice versa was stressed in the school curriculum. The nature of science, its social aspects, and its human character were sought to be described through the study of the history, philosophy and sociology of science.

Theoretical Framework for the NOS Study

This study on pre-service teachers used the framework of Lederman et al (2002). According to him the debates in this area had been far removed from the concerns of teachers and students. '*These disagreements (e.g. The issue of the existence of an objective reality compared with phenomenal realities is a case in point) are generally far too abstract for pre service elementary teachers / students to understand and far too obscure/esoteric to be of any consequence to their daily lives'* (p 499). He developed a framework using characteristics about the nature of science which were less abstract and which dealt with ideas such as, the difference between laws and theories, which often cause misconceptions among students and teachers. The present study makes use of this framework to analyse the views of pre-service teachers and to subsequently develop 'Learning about Science' (LAS) Teaching Modules for them.

The dimensions on the nature of science in Lederman's theoretical framework are:

1. The Tentative Nature of Scientific Knowledge
2. The Empirical Nature of Scientific Knowledge
3. The Theory Laden Nature of Scientific Knowledge
4. The Creativity and Imaginative Nature of Scientific Knowledge
5. The Social and Cultural Embeddedness of Scientific Knowledge
6. Observations, Inference and Theoretical Entities in Science.
7. Myth of The Scientific Method
8. Scientific Theories and Laws

The Sample Group

B.El.Ed. Course

Generally the one year teacher education degree course is offered after graduation and focuses on developing teaching skills in one or two subjects. These teachers are trained at secondary level and teach one or two school subject(s). On the other hand B.El.Ed (Bachelor of Elementary Education) is a four year integrated course in elementary teacher education. Presently this programme is offered only in eight colleges of the University of Delhi. Around three hundred students complete this course every year. The elementary teachers are expected to teach all subjects till class VIII. Therefore, it is more important that elementary teacher education should focus on developing an understanding of teaching of all school subjects.

Theory Papers in the B.El.Ed. Course

There are two compulsory papers in science: 'Core Natural Science' and 'Pedagogy of Environmental Studies' in the first and third year respectively. Therefore, data was collected from students of these two years from the three selected colleges. A total of one hundred and fifteen pre-service elementary teachers (students) participated in my research.

The first year course is a core paper titled as C1.3 'Core Natural Science', in which students are encouraged to revisit the content they have already studied at the secondary level. They review their understanding of science concepts and clarify their misconceptions, simultaneously focussing on skills of scientific enquiry like observation, estimation, measurement, prediction, hypothesis formation, experimentation, and inference.

'The Nature of Science' is not directly mentioned in the syllabus. It is addressed very briefly and quite inadequately only through only one unit. It is left to the individual teacher to decide whether she wants to address the issue of nature of science or not. The other three units focus on science concepts from physics, chemistry and biology. Each of the concepts brings with them a long history of struggles to develop their meanings, it was important to use these to see how students relate to the nature of scientific development. For instance, topics from the syllabus like structure of atom, modern form of periodic table or laws of motion all are not frozen in time but are themselves part of an often long and tumultuous history of scientific struggle. As in discussion of the teaching module IV on 'the structure of atom' was used as an example to develop an understanding of students about the tentative and empirical nature of scientific knowledge.

The other compulsory pedagogy course in science is placed in the third year titled as P 3.3 Pedagogy of Environmental Studies through which students are exposed to the significance of EVS as a curricular area at primary level.

Similar to the previous course, the nature of science does not appear in the syllabus. The words 'the method of science' tends to develop the notion that there is 'the method of science'. However, there is scope for discussing nature of science through 'alternative framework' but it generally goes unaddressed. Thus, in the current science syllabi of the B.El.Ed. programme, the nature of science is inadequately addressed.

The Sample

Three colleges located in different parts of the city - one in the North – West Delhi (a pre dominantly rural area), the other in South Delhi and the third in University Campus were chosen for the study.

In these three colleges pre – service teachers from the first year and third year participated in the research. Overall data from one hundred and fifteen pre – service teachers were collected.

How can an understanding of 'NOS' be developed?

During discussion with pre service teachers I found that majority of them have the notion that scientist is a bearded male with a strange hair style or a bald head who wears a white coat and spectacles. The majority of children believe that science is all about mixing chemicals to invent things in a laboratory and scientists are the ones who do these inventions working with test tubes and beakers. They perceive a scientist to be nothing more than a glorified chemist. Children of all age groups from four to eleven years found to hold 'stereotypical image' of scientists. These ideas are similar to one found by researchers working with the children's (Newton and Newton (1988, 1993), Rampal (1993), Masih (1998)) and teachers' perception Haidar (1999), Craven, Hand and Pravin (2002), and Rubin, Bar, and Cohen (2003) of science and scientists.

The research conducted in the area mentions two types are approaches. One is the implicit approach, in which hands on activities are organized in science classrooms. While doing activities students involve in formulating hypotheses, designing and conducting an experiment, recording observations, then making inferences and reaching at conclusions. By this way, students are engaging themselves with the processes of science. It is assumed that an understanding of nature of science is developed side by side as a by-product of engagement in science based activities. On contrary, in explicit approach an improvement of views on the nature of science should be planned through objectives, instructional attention and assessments. It intentionally draws learners' attention to aspects of the nature of science through discussion, guided reflection and specific questioning in the context of activities, investigations and historical examples (Akerson, Abd-El-Khalick and Lederman (2000), Abd-El-Khalick et al. (2004)).

The implicit and explicit approaches basically differ from each other in the extent to which learners are encouraged to think about and reflect on the concept of the nature of science. In the implicit approach, it is assumed that learners will automatically understand the nature of science while doing science activities. On the other hand, in explicit approach there is a clear cut focus on the nature of science. The nature of science should be explicitly taught like other components of science curriculum and should not be confused with didactic teaching. The understanding of the nature of science should be intentionally targeted and planned for in the same manner as abstract scientific concepts and theories.

In the present research 'Learning about Science' (LAS) Teaching Modules designed during the course of research addressed the nature of science explicitly. Some of the misconceptions that are challenged through this research are:

- Scientists conduct research in a similar manner. The observations noted carefully will result in the same scientific knowledge.
- Experiments are the route to scientific knowledge.
- All scientists follow 'the scientific method' in which certain steps such as defining a problem, formulating a hypothesis, designing experimentation, making observations and drawing conclusions are followed.
- Science and scientists are objective.
- Objectivity is an important distinction between science and other subjects - social studies, language.

Learning about Science (LAS) Teaching Modules

For the present research six teaching modules were developed. Each teaching module has some material to read, think and then express their opinions. Pre –service teachers' ideas were challenged again and again through different instances. These teaching modules were developed around questions like – Can there be controversies in Science?, What is technology?, How do scientists work? , Does scientists' opinion influence scientific knowledge? , Do scientists make discovery by chance?

The following six LAS Teaching Modules were developed:

i. Is there one 'Scientific Method'?: Looking at Environmental Campaigns
ii. Debates over Bio- fuels
iii. Controversies in Science and Media: Genetically Modified Foods.
iv. Drawing Inferences from Observations: Structure of the Atom
v. How do Scientists come to a Theory?
vi. Scientists and the Language They Use

The representations of the dimensions of Nature of Science in the Teaching Modules are shown in appendix II.

For instance a module on controversies raises the issues of Silent Valley, "Yamuna Satyagraha: Campaign to save a River", Prof. G. D. Agarwal (Retd. from IIT Kanpur) is on fast unto death to save river Ganga from a series of dams or barrages between Goumukh and Uttarkashi.

Then students were asked to reflect on questions like:

- Why do think there is the controversy?
- Can you think of an example where two groups of scientists have offered contradictory claims?
- Why do you think that scientists have different opinions?
- Do you think that one group of scientists is 'right' and one is 'wrong'? On what basis do you decide on this?
- Do you think scientists can differ on conclusions that they draw?
- If scientists follow 'one scientific method' then how can it happen that they come to different conclusions? Do you think there is one 'scientific method'?
- Why is that scientists generally do not come up in the open and protest against such decisions by the government?

The modules were tried on the sample group followed by discussion on pre service teachers' responses.

Findings

The following are the findings on different dimensions of the 'nature of science':

The Tentative Nature of Scientific Knowledge

Initially, over half the students held the naïve view that scientific knowledge, including theories and laws, does not change, but is final, fixed and static. However, Teaching Modules based on controversies in science, helped students to see the tentative and contested nature of scientific knowledge. The example of structure of the atom helped about two third of students recognising that scientific knowledge is never absolute and final but tentative in nature.

The Empirical Nature of Scientific Knowledge

A significant number of students simplistically interpreted 'scientific knowledge' as 'knowing is seeing'. Initially slightly less than one fourth students held the position that "*Scientific observations will not differ very much even though scientists believe different theories. If the scientists are indeed competent their observations will be similar"*. Thirty percent of students held the naïve view (in the teaching module on atoms) that '*for scientists to know and be sure about the structure of the atom, they have to see them; scientists cannot be certain unless they see*'; '*scientists would learn about atoms only by actually seeing them' 'Evidence must be directly observable'*. More importantly, even after Teaching Modules they were not able to understand it. Thus, this dimension of NOS needs more intensive intervention that challenges their deeply entrenched views.

The Theory Laden Nature of Scientific Knowledge

It was found that slightly above thirty percent of students held the view that observations are objective and independent of the observer. Only one fourth students seemed to recognize that depending on their theoretical framework scientists will think differently and that will affect their observations. In the Teaching Module on GM Foods, sixty percent students subscribed to the contemporary accepted view that '*scientists looks at data from their point of view, they interpret it differently, it is their perspectives on their experiments'; 'different backgrounds, knowledge, opinion and experiences inform scientists and what they believe and see'*.

The Creativity and Imaginative Nature of Scientific Knowledge

After sufficient exercises with students using a picture of fossils of dinosaurs, three fourths believed that creativity and imagination are involved at every step in the scientific investigation. They expressed views like '*not all data is observed, so there is a need for imagination to fill in the gaps'; 'scientists have to be creative to design, and alter the experiments if they don't work for the first time*'.Students held naïve views about the role of creativity and imagination such as *'creativity and imagination cannot be involved in depicting how atoms look like';*

The Social and Cultural Embeddedness of Scientific Knowledge

In the Teaching Module on Bio-fuels three fourth students recognised that interpretations of the same data may be different for different scientists. There may be two different groups of scientists reaching different conclusions. In the controversy on 'Silent Valley' and 'GM Foods' about half the students believed that both groups of scientists can be right and it is difficult for scientists to understand each other's work.

Scientific Theories and Laws

In the teaching module on GM foods about half the students developed an understanding that scientific knowledge is also different from that of an opinion. Scientific knowledge is proven or tested and objective which become theories and laws whereas opinions are personal and subjective.

Observations, Inference and Theoretical Entities in Science

Some students were unable to distinguish between what is observed and what is inferred. The teaching module on the structure of the atom dealt with the distinction between observation and inference.

Myth of The Scientific Method

About seventy percent of students chose the naïve view that there is a definite pattern of doing science. About sixty percent students believed that scientists follow 'the scientific method'. After raising the issue of 'the scientific method' again and again in different modules, almost half the students still held the view that *'scientists can resolve disputes by experimental evidences'; 'scientists are objective and experiments can provide answers to all questions'; 'if scientist follow the scientific method their results will be same'*. Forty percent identified scientific method as a step by step procedure. Only half expressed views such as '*in a controversy, if scientists reached different conclusions, then they must be following different methodsthat followed some general rules and procedures'*. However number of students referring to 'different methods' was very low. Thus the myth of the scientific method still seemed to persist in about half the students, indicating how deeply entrenched this notion is and the need for different interventions to dramatically challenge it.

Conclusion

Teaching Modules were developed to engage students in issues related to the nature of science. The attempt has been made that students should de-learn some of their ideas like 'science is objective' and develop contemporary accepted ideas. The students' views changed considerably but in varying manner as some ideas are either more deeply entrenched or not sufficiently challenged through modules. By the end of the study, there was a decline in the number of students holding naïve views on different dimensions on the nature of science except on the myth of the 'scientific method' and the empirical nature of knowledge.

Students' perception of scientists as being individuals involved in recording objective observation, changed to accept that scientists are like us, part of society, have personal opinions and biases in evidence collection and worried about their reputation and funding. However, they do a *"research in systematic manner either alone or* *in groups"*. The examples of Rosalind Franklin and Marie Curie helped in sensitising students towards the issue of gender discrimination in the pursuit of science.

There is a need for conscious and deliberate efforts to challenge their views on these dimensions of the nature of science. Thus, improvement of students' views of NOS was not parallel and consistent among the different dimensions of the nature of science (Khishfe 2008; Akerson et al 2000; Brickhouse et al 2000). The change in students' views on the nature of science is a difficult process and appeared to take place gradually and progressively (Driver et al 1996, Posner et al 1982).

Implications for Teacher Education Programme

At present the science curriculum in pre service teacher education programme at elementary level has superficial coverage of too many concepts. The content 'load' does not provide scope for an in-depth analysis of how different concepts have evolved over a period of time.

Few concepts but an in depth study of those concepts can help in building an understanding of the of science. Short narratives or biographies of scientists can be a good starting point to introduce students to the processes of scientific struggle. There is a need for a conscious and deliberate intervention in the curriculum of secondary schools students and pre service teachers.

Another area of intervention is the integration of NOS into the curriculum in the course on pedagogy of science (for B.El.Ed.) of including it as a discrete topic. E.g., topicalissues should be an integral part of the curriculum and teachers should be sensitised towards teaching it. This idea was used in Teaching Modules, where it was found that contemporary controversial issues help engage students in developing an understanding about the nature of science. Therefore, ncan also be used as a good resource to initiate discussions in the class around science related news.

Additionally, NOS understanding should also be appropriately addressed in examinations. Pre-service teachers should be given extensive experience in teaching and assessing the nature of science. field based project can also be used in which pre service teachers meet real scientists and talk to them; visit actual laboratories and observe how scientists work; get an idea about out how scientists do research. However, some efforts have been made in forums for popular science communication with a special focus on the nature of science. This can be adopted into the curriculum for elementary teacher education. As part of their preparation for school internship, pre-service teachers can be oriented for preparing the nature of science lesson plans to examine and develop the NOS explicitly in classrooms.

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Instructional Modeling and Coaching Enhance Science Teachers' Inquiry-Oriented Teaching Skills

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*We employed an "instructional coaching model" to provide professional development to middle grades (6 – 8) science teachers. Funded through the Mathematics & Science Partnership Program (MSP), Project QTL (**Q**uality **T**eaching & **L**earning) involved teachers over a course of three academic years and four summer sessions (Summer 2007 – Summer 2010). Professional development included summer institutes as well as academic year coaching and implementation. Summer institutes focused on science content learning in the context of the 5E model of the Learning Cycle as the instructional framework to enhance more authentic inquiry-oriented teaching and learning of science. During the academic years, instructional coaches mentored, guided and supported teachers in the implementation of 5E style instruction. Teacher enhancement toward more inquiry-oriented, 5E-based instruction was documented by coaches and an external evaluator through classroom observation logs. Content mastery of teachers was assessed through content tests given as pre-and post-tests. Pre-tests were given at the beginning of each summer institute and post-tests at the end of the following academic year. Results indicate significant improvement over the three-year duration in both teacher content mastery and their ability to provide more inquiry-oriented learning experiences to students.*

Who was involved in Project QTL?

Project QTL involved middle grades science teachers from the following three school districts in the southwestern region of North Carolina, USA. Of these, one school district includes both rural and urban areas, another one is rural, while the third is semi-rural.

Teachers from all three counties participated in the project on a voluntary basis. Over the course of three years (2007 – 2010), a total of 70 teachers were involved in project activities. In terms of the grade levels involved, the project was originally targeted for 7^{th} and 8^{th} grade teachers, who participated during all the three years of project funding cycle. 6^{th} grade teachers were included during the final (third) year of the project. Overall, though, each of the three grade levels was represented by approximately 33% of the total population of 70 participating teachers.

Each school district employed a science instructional coach in full time capacity to work with its teachers throughout the duration of the project. Each of the three coaches were experienced, in-service high school science teachers within their respective counties, prior to being hired by Project QTL. The role of these coaches was to mentor, guide, support, advise, and help teachers grow in their ability to implement inquiry-oriented instruction through the use of the 5E model of the Learning Cycle. To be sure, at no point were the coaches expected to assist the school administration in evaluating these teachers. They were always strictly 'mentors', never 'evaluators'.

Appalachian State University (ASU) partnered as the institution of higher education and offered summer institutes for the project. These summer institutes focused on enhancing content knowledge of the teachers in topics found in middle grades science curriculum of the state. The Mathematics & Science Education Center at ASU provided administrative support for the summer institutes. The author, an ASU science education faculty member, in collaboration with the three instructional coaches and assisted by three graduate students from ASU's department of biology, designed, organized and conducted each of the four summer institutes. The Blackburn Consulting Group (www.barbarablackburnonline.com) served as External Evaluators of the project. Staff of this group provided independent external evaluation of the fidelity of project implementation as well as documented change in instructional practices and content knowledge of participating teachers. At the end of each academic year, the evaluation group provided formal written annual evaluation report to the project director.

How does Project QTL fit within Current Science Education Reform?

The goals of Project QTL were twofold: To enhance teacher understanding of scientific concepts included in the middle grades science curriculum and, equally important, to enhance their ability to teach these concepts in ways that allow students to experience professional scientific practices in their science learning.

A *Framework for K-12 Science Education* (National Research Council, 2012), identifies the following "practices" as reflective of the work of professional scientists (Dimension 3):

- Asking Questions
- Modeling (mental, physical, mathematical, and/or computer simulated models to generate approaches to answering the questions)
- Devising Testable Hypotheses
- Collecting, Analyzing and Interpreting Data
- Constructing Explanations and Critiquing Arguments (based on evidence collected)
- Communicating and Interpreting Scientific Information
- Applying and Using Scientific Knowledge

The *Framework* sees this of "essential practices as core for any education in the sciences" (Chapter 5, page 8). This implies that experiencing these practices ought to be as integral a part of science learning as is the acquisition of current scientific knowledge. Thus, science instruction should be intentional in allowing students the opportunity to experience and engage in these practices. The current *National Science Education Standards*(NSES; National Research Council, 1996) also promote most of these same practices in what they call 'Science as Inquiry', which is part of the Science Content Standards in the NSES. Moreover, the Science Teaching Standards in the NSES promote organizing instruction around 'Science as Inquiry' Standards. Therefore, it can be argued that classroom learning experiences that promote these "practices" of science has been a long-standing and desirable goal of school science education.

In order to promote this goal of science education, Project QTL employed the 5E model of the Learning Cycle (Trowbridge & Bybee, 1996; 5 phases in the cycle, each starting with an E, hence the 5E model) as the pedagogical approach during the summer institutes and then mentored participating teachers to use the 5E model in their own classrooms during the academic years. Over the years, increasing amount of evidence has accumulated in favor of the Learning Cycle approach as an effective pedagogy to promote "inquiry-based" science learning (Allard & Barman, 1994; Barman, 1992; Barman, 1988; Bybee, 1997; Odom & Kelly, 2001; Purser & Renner, 1983; Saunders & Shepardson, 1987; Stepans et al., 1988).

As teachers participated in the summer institutes, they experienced learning science content through the vehicle of the 5E model used by the author. Thus, as students during the summer institutes, they had first hand experience of what effective 5E based instruction looks like, while learning the science content that they would teach in their own classes. Near the end of each day of the summer institutes, participants engaged in a time of community reflection and sharing to discuss the elements of the 5E model that they experienced that day. This reflective practice was employed to ensure that the teachers recognized the essential elements of the 5E model, as well as understood the characteristics that made them effective. Such a nexus of effective pedagogical modeling and explicit reflective discussion of the model is crucial to teachers understanding and internalizing the pedagogy in order to be able to implement it in their own classes. Moreover, the nexus of content learning with pedagogical modeling and explicit reflective discussions directly connects with Professional Development Standards A, B and D of the NSES, which respectively state:

- Professional development for teachers of science requires learning essential content through the perspectives and methods of inquiry;
- Professional development for teachers of science requires integrating knowledge of science, learning, pedagogy, and students; it also requires applying that knowledge to science teaching;
- Professional development programs for teachers of science must be coherent and integrated.

(National Research Council, 1996, pp. 59, 62, 70)

Through the summer institute learning experiences focused on both content and pedagogy enhancement, followed by expectations to implement the 5E model in their own classes, and mentored by instructional coaches throughout the academic years over a duration of three years, Project QTL ensured lasting change in teachers instructional practice and professional development toward more inquiry-oriented science instruction.

What did Project QTL Do? (Major Features of the Program)

Project QTL was designed with two premises of professional development that have long been found effective in bringing about lasting reform (Blunck & Yager, 1996; Darling-Hammond & McLaughlin, 1995; Guskey, 1995; Lieberman, 1995; Sparks, 1983) and boldly promoted in the NSES (National Research Council, 1996, Chapter 4). These premises are:

9. Professional development must be sustained over a long period of time.
10. There should be both an expectation and appropriate support mechanisms for teachers to implement in their classes what they were learning in the professional development program.

With these premises in mind, Project QTL involved teachers in professional learning experiences over a course of 3 years. Each year, there was a one-week long summer institute, separately conducted for teachers of different grade levels, followed by academic year implementation of pedagogy experienced and learned during the summer institute. Altogether, the project offered a total of 4 summer institutes and 3 academic year implementation cycles.

The Summer Institutes

The one-week long summer institutes were designed to enhance teachers knowledge of the science content as well as have them experience, as students, the 5E model of the Learning Cycle pedagogy. In other words, the science content was taught to them using the 5E model. The purpose of this nexus of content with 5E pedagogy was to enable teachers to implement the same pedagogy in their own classes. During the spring semester prior to each summer, a survey was given to teachers to determine the content topics (from the state science curriculum) that should be addressed during that summer. The ASU faculty member and the three county level instructional coaches then met to plan the summer institute based on teacher responses on this survey. The topics that received majority votes for 'not confident/comfortable with this topic' were chosen to become the content focus of that summer's institute.

Academic Year Mentoring & Implementation

Since the goal of Project QTL was to enhance science teaching and learning in participating counties' middle schools, teachers were expected to use the 5E model, experienced during the summer institutes, in designing science learning experiences for their students during the academic years. In order to ensure the implementation of the 5E model, teachers were given some planning time during the summer institutes to meet in grade level teams by county, so that they could begin developing 5E-based instructional plans and receive feedback from the institute instructor on their initial plans.

During the academic year, county level instructional coaches worked with the teachers on a regular basis to help them implement the 5E model. The goal here was to have teachers implement the 5E model in teaching at least those topics that they experienced during the preceding summer institute. Thus, it was intended that by the end of the third year of the project, most teachers should become adept at using the 5E model and teach their entire science curriculum using this approach effectively. Coaches' work with the teachers during the academic year included the following activities.

Classroom observation of lessons, followed by conference with individual teachers to provide feedback and suggestions: Coaches used a formal classroom observation protocol that helped them identify teachers' strengths and areas that needed improvement. This observation protocol was adapted from Inside the Classroom Observation and Analytic Protocol developed by Horizon Research (www.horizon-research.com/instruments). The cover sheet information of demographic data and a breakdown of the classroom environment was adapted from an observation tool developed by the Southern Regional Education Board (www.sreb.org). Using a formal observation protocol helped the coaches in mentoring and guiding the teachers toward continual refinement of their ability to effectively implement the 5E model in their classrooms. The coaches also used a formal log to document the proceedings of conferences with individual teachers.

Acquisition of resources and materials to implement 5E-based lessons: In consultation with the teachers, the coaches identified, obtained and made available the materials needed by teachers to conduct various laboratory activities, demonstrations, experiments, etc., within the 5E format. Project grant funds were used to buy the materials that needed to be purchased.

Weekly school level planning meetings (Teachers Professional Learning Community): The coaches maintained a formal schedule of visitation to schools so that they could regularly observe teachers at specific school as well as meet with all project participants of that school for a weekly planning meeting. During these weekly planning meetings, they discussed lessons that were being taught during that week and addressed issues related to the 5E model as they pertained to those lessons.

Monthly district level planning meetings (Coaches Professional Learning Community): To maintain their own growth and learn from each other, as well as keep track of the progress of project implementation at the classroom level, the coaches and curriculum directors of all three participating counties met as a PLC once a month. A formal, tentative agenda was developed by the project director in advance of the meeting and circulated to all partners, including the ASU faculty member. Agenda was finalized prior to the meeting based on any feedback received from the partners on the tentative agenda. A fixed item on the agenda for these monthly PLC meetings was reports from each coach on the progress of work being done in their respective counties.

The overarching goal of all the summer and academic year activities was to ensure that by the end of the project funding cycle middle grades science instruction in all three participating school districts will be highly inquiry-based, using the 5E model and providing challenging and engaging hands-on/minds-on activities for students to develop a robust understanding of the topics included in their science curriculum.

What did Project QTL Accomplish?

The ultimate goal of any in-service professional development program ought to be teacher enhancement in content, pedagogy, use of technology, or a combination of these, which translates into better student engagement and achievement in the classroom. Project QTL was designed to enrich teachers knowledge and understanding of the science content they have to teach, and enable them to use the inquiry-oriented 5E model of the Learning Cycle effectively to teach science at middle grades. To be able to assess and document project impact on teachers in these two areas, we formally collected and analyzed data that is described below.

Teacher Enhancement

Content Knowledge Enrichment: Since the summer institutes focused on content knowledge enrichment of teachers, we administered multiple-choice tests on the appropriate topics as Pre-Post Assessment. The pre-test was administered on the first day of each summer institute and the same test was administered as post-test at the end of the following academic year. For example, if the pre-test was given in summer 2007, the post-test would be given in late May/early June 2008. The reason we gave the post-test at the end of the following year, rather than at the end of summer institute, was because teachers' content knowledge enrichment was continued by the instructional coaches through the academic year.

The content tests were developed on the premise that teachers understanding of the topics must develop to a deeper level than that required by the middle grades curriculum for the students to learn. Hence, we selected questions from a Prentice Hall High School Examview test bank for the topics that were addressed during each summer institute and through the following academic year. Teacher performance on these tests was analyzed by the external evaluator, subjecting the mean scores on the pre- and post-tests to ONE WAY ANOVA. The analysis found statistically significant enrichment in teachers' content knowledge during the first and third year of the project.

Use of 5E-based, Inquiry-oriented Pedagogy: Project impact on teacher use of 5E-based, inquiry-oriented pedagogy was documented through classroom observations made by the coaches using the observation protocol mentioned earlier. These observation logs were then given to the external evaluator to independently analyze and corroborate with her own classroom observations of teachers. Quantitative and qualitative analyses of the instances of inquiry-oriented instruction indicated in the observation logs were conducted by the external evaluator. These analyses indicated that during the first year (2007 – 2008) there was a pattern of slow growth in the use of inquiry-oriented pedagogy. This can be explained by the fact that for many teachers, the 5E model was a brand-new approach to teaching science and the first-ever modeling of this approach for them was during the summer institutes of 2007. During the second year (2008 – 2009), the observation log analyses revealed a markedly increased pattern of the use of the 5E model, with greater increase noticed during the spring semester. Overall, 87% of all lessons observed showed elements of inquiry-oriented pedagogy during the second year. Somewhat difficult to explain were the results for the third year (2009 – 2010). During this year only 83% of all lessons observed showed elements of inquiry-oriented instruction. One would expect that by the third year teachers should become more proficient in the use of the 5E model because by now they have experienced this model over three summer institutes. However, what is encouraging is the fact that when observation logs of teachers who participated in the summer institutes were compared with logs of teachers who did not participate in the summer institutes, it was found that summer institute participants had a much higher use of inquiry-oriented pedagogy than non-participants. This implies that seeing explicit modeling of the pedagogy and experiencing it as students is very important for teachers if they are to implement it in their own classes.

Development of Teacher Leadership

Of particular note during the final year (2009 – 2010) was the emphasis to shift leadership to the teacher-participants. The intention behind this emphasis was to generate sustainability of the project's goals and accomplishments beyond the funding period. Throughout the year, coaches encouraged teachers to take leadership roles during the Teachers PLC meetings. Teachers began creating norms for the meetings, and prior to each meeting, a teacher-leader created and distributed the agenda. Discussions were facilitated by the teacher-leader for the meeting, and the coach became more of a background resource. It is evident through the meeting agendas during the third year that teachers took ownership of the meetings, and as a result, the meetings became teacher-led, rather than coach-led. With teacher leadership of their PLC meetings, the PLCs are much more likely to continue after the grant, even when there is no district level coach anymore.

Also, teachers began using electronic methods, such as email and bulletin boards/websites to communicate with each other and share ideas. Although there was variation by district and individual teacher, many teachers embraced the electronic communication to collaborate regarding resources and effective teaching. Finally, the coaches tracked whether contact was coach-initiated or teacher-initiated. During the early stages of the project, there was some reluctance from teachers to utilize the expertise of the coaches. However, through the three years, coaches were able to develop a collaborative relationship with teachers. During the final year of the project, 40% of the contacts with the coaches were initiated by teachers, indicating that teachers were beginning to take more responsibility of seeking help toward improvement of their instructional practice.

What Lessons can be learned from Project QTL's Model?

There are TWO characteristics features of Project QTL that coincide with the two premises on which this project was based.

1. Immersion of teachers in summer learning of content and pedagogy, followed by academic year implementation over a course of three years.
2. Employment of instructional coaches dedicated to mentoring, supporting, guiding, and assisting teachers in their own county during the academic year implementation process.

Summer learning institutes focused on the nexus of content and pedagogy, followed by academic year implementation is not necessarily a novel idea. Many professional development programs have adopted this model of professional development. However, the important feature here is the duration of the implementation cycle. The lesson we learned, albeit not surprisingly, is that teachers understanding and comfort level with new pedagogies develops at different rates, just like our students develop understanding of concepts at different rates. Thus, for some teachers, the three-year duration was not enough to reach the level where they can effortlessly implement the 5E model effectively in their classes. Our recommendation is that a program like this one should be designed and funded for at least 5 years in order to maximize project impact on teacher learning and classroom implementation.

The employment of instructional coaches, whose job responsibility is solely to mentor the teachers and address their needs regarding the implementation of *new* pedagogy (new to those teachers, not necessarily to the field of education) on a regular basis, is not a commonly observed component of many professional development programs. If one is to adopt this "coaching model" and expects it to produce positive results, the following must be considered carefully in selecting the coaches. An instructional coach must:

- Understand how adults learn;
- Understand the change process;
- Be accepting of change;
- Be a promoter and facilitator of instructional change;
- Model and facilitate communication at multiple levels and from multiple stakeholders;
- Be able to develop rapport with and seek support from both school and district level administration;
- Be able to develop rapport with the teachers so that they can trust and confide in the coach without fear that the coach might be serving as the "eyes" and "ears" of the administration; and
- Be able to develop leadership among teachers rather than always wanting to lead.

The success of the "coaching model" depends to a large extent on the quality of the coach. Fortunately for us, we had experienced high school science teachers, in all three participating counties, with qualities, attitudes and aptitudes that enabled them to become effective and successful coaches in their respective counties.

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Measuring the Mustard Seed: First Exercise in Modelling the Real World

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Constructing, reading and understanding graphs is an interdisciplinary and important skill in today's world. Though being such an important skill students are not taught explicitly to develop this important skill. Also there has been an urge in the literature for the students to use real world data to make sense of the concepts that they learn. In general students are not provided with opportunities to make the skill explicit, and link it up with their life experiences the concepts and subjects that they learn. We present here a simple task which provides the students a context in which real world data is collected, and used to construct a simple linear mathematical model. This task connects different skills like measurement, graphicacy, mathematical modelling and at the same time also helps a two way transition between the abstract mathematical world and the concrete physical world.

Introduction

Mathematical quantitative models are a way to understand the natural world in terms of mathematical symbols and relations. All the models that we have present us with a way to understand, predict and analyse the natural phenomena around us. *A mathematical model is an abstract, simplified, mathematical construct related to a part of reality and created for a particular purpose* (Bender, 1978). Different authors give different interpretations for mathematical modelling and there is some ambiguity in the definitions (Pinker, 1981), but in essence the above definition captures what we mean by a mathematical model in this study. Modelling thus is the hallmark of science. In a particular model the relation between various parameters can be at times quite demanding and complex. We need to present the students with various opportunities to explore the meaning of models in the world around them. Most of the problems students face in textbooks are aimed at giving practice in mathematical manipulations, rather than at giving physical insights, and little scope is provided to them regarding thinking about mathematization of real-life situations (Kapur, 1992).

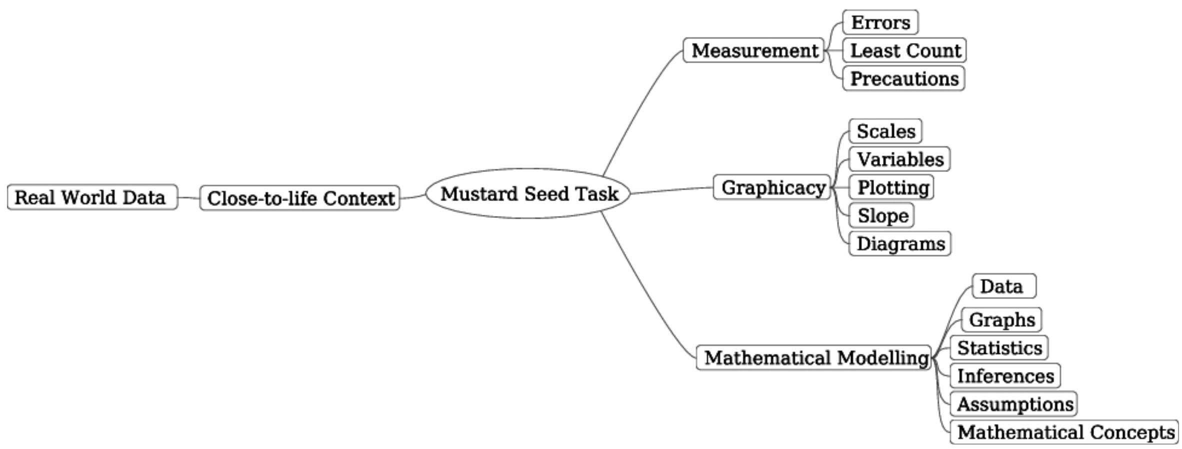

Figure 1. Concepts and related activities for the mustard seed task.

In case of mathematical modelling the students make use of the mathematical concepts that they have learned find patterns and relationships in the data. This requires them to use multiple symbolic systems (tabular, graphical and algebraic in this case) and to understand the relationships between them. Leinhardt et. al suggest that functions and graphs represent one of the earliest points in mathematics in which a student uses one symbolic system to expand and understand the other (Leinhardt, Zaslavsky, & Stein, 1990) This in turn is related to graphicacy, which is defined as the ability to understand and present information in the form of sketches, photographs, diagrams, maps, plans, charts, graphs and other non-textual, two-dimensional formats (Aldrich &

Sheppard, 2000). But if graphs and tables are taught simply as procedural algorithms, then the potential to extract explanations from the patterns and trends observed will be restricted. If children do not understand the purpose of graphs then data handling will not impinge upon the design or the execution of the investigation (Rodrigues, 1994). It has been suggested that school children should be actively involved in collecting “real world” data to construct their own simple graphs. In this way, the application of mathematics to the phenomenon under observation, might enhance students’ concept development, particularly operational concepts, correlations, and build and expand the relevant mathematics schemata they need to comprehend the implicit mathematical relationships or theoretical models expressed in graphs (Curcio, 1987). Also, if we take examples from real world to mathematics we can further enhance the development of relevant concepts. This implies encouraging children to design experiments to help them ascertain and determine relationships, not simply teach them the mechanics of graph work (Rodrigues, 1994). Monk suggests that graphing is not a skill which is to be imparted once and for all, but it should be gradually developed across the grades. Graphing must be repeatedly encountered by students as a means of communication and of generating understanding, as the students move across the grades (Monk, 2003). Also in the National Curriculum Framework of 2005 there is a call for emphasis on making connections between mathematics and other subjects. When students learn to draw graphs the functional relationships in science are to be emphasized (NCF, 2005). But in case of Indian textbooks a survey shows a limited use of graphs in the text (Dhakulkar & Nagarjuna, 2011). The graphics in textbooks include pictures, diagrams and graphs, but graphs are rarely used in the textbooks in a way which would provide these relationships.

The problems related to graphicacy are explored in detail by Roth and others in *Critical Graphicacy* (Roth, Pozzer-Ardenghi, & Han, 2005), where the authors address some overarching question about graphicacy: ‘What practices are required for reading inscriptions? ’ and ‘Do textbooks allow students to develop levels of graphicacy required to *critically* read scientific texts? They state “…our aim as critical educators is not just the provision of opportunities for students to become graphically literate; rather, we want students to develop critical graphicacy, that is, we want them to become literate in constructing and deconstructing inscriptions, the deployment of which is always inherently political.”

To address the above mentioned issues one of the tasks that we came up with was the measuring of the mustard seed diameter, which forms the basis of this report of an ongoing work. This is part of a larger work on providing students with opportunities to use real world data for constructing, analyzing and developing understanding of the graphs. The task can be seen as a first step towards mathematically modelling more challenging problems from real life situations which have little scope in the standard school texts.

We present here one task for providing the students with opportunities that make this possible. The task is that of measuring the average diameter of the mustard seeds. The objective of the task is to provide students with a context to link up different concepts which span across disciplines and provides the learners with a first hand opportunity to build and test a mathematical model. There is a chance that these concepts would otherwise remain unrelated. The three main concepts as shown in Figure 1 that are linked to the mustard seed task are measurement, graphicacy and mathematical modelling. Each one of these tasks presents its own challenges for the students.

The Indian kitchen is a versatile place where many spices and ingredients mingle to produce a variety of cuisines in different parts of the country. Though each part has a unique style of cooking, there are many things that you will find in each kitchen. One of them is the mustard seed, scientific name *Brassica nigra*. In many of the cuisines the mustard seed is a must, to give a *tadka* or flavour to the food. Thus common availability of the mustard seeds in almost every kitchen provides easy access to the students for doing the measurements. There are two varieties of mustard commonly found in the markets, one variety has seeds almost double size (~2 mm) of the other one (~1 mm).

The size of the seeds is just right enough to make measurements possible with help of a ruler, also they being almost spherical and their easy availability makes them ideal for such experiments. The purpose of this task was to expose the students to to the process of collecting, representing and analysing the data.

The Sample

Most of the students were from the ninth grade, and were selected for a summer camp by the schools themselves, with each school being represented by two students. The medium of instruction at the school for the students was either Marathi or English. Most of the students understood Marathi and Hindi well. Some students had problem in understanding English, so for them the instructions were given in Marathi or Hindi. This was a week long course, in which students were given various activities related to science in general and astronomy in particular. The general aim of the workshop was to introduce students to some aspects of naked eye astronomy and scientific experiments. The workshop included many tasks and tests (pre and post) in which the students participated. One of the tasks that was given to the students was to measure the diameter of the mustard seed. In all there were 4 batches of students, we are presenting the data from batch number one. There were a total of 28 students in this batch.

The Task

All the students in the class were familiar with mustard seeds. The task given to the students was to measure the diameter of the mustard seed. The students were familiar with the properties of a circle (like area and circumference) and a sphere (volume). Two examples which are similar to the mustard seed task involving indirect measurement were discussed in the class. One of the tasks was indirect measurement of width of a thread. This is usually done by winding the thread on a object (for example a pencil) and finding the length for a given number of turns. We would get the average width by dividing this length by the number of turns. The second task that was discussed was to find the thickness of the papers of a given book. This task also involves measuring the length for a given number of papers and then the average thickness is found out by dividing the length by the number of pages. We could use either of these two tasks or the mustard seed task as the approach to modelling.

After these two warm up discussions the students were asked to guess the approximate size of the mustard seeds, for this purpose some mustard seeds were shown to them in the classroom. During the discussions that ensued the students came up with answers like few centimetres to few millimetres.

In the next part of the discussion the students were asked to come up with ideas for measuring the diameter of the seeds. The idea of using a ruler for measuring the diameter was not disclosed to them. Some of the students came up with some ingenious methods of measuring the diameter. One of the students suggested that a thread should be wound on the seed, and then the length of the thread can be measured easily with help of a ruler. Another student suggested an even more elaborate method: we can find out volume of displacement of water due to a seed and then from the volume of the water we can find out the volume of the mustard seed and from the volume we can find out the radius (and hence diameter). The idea that was in general floating around in the discussion was that we have to measure the diameter of only one seed.

To counter this the instructor asked the students to look at the mustard seeds and to tell whether all of them were of exactly same size. To this students responded that they were not of same size. Some of the students responded to this by saying that an average of many values need to be taken. This way the idea of doing multiple measurements and taking averages was brought in.

Then the discussion led to using the task of measuring the diameter of the mustard seed with help of a ruler (1 mm as the least count). In this case the students were told to take measurements of 5, 10, 15, 20, 25 and 30 mustard seeds. The measurement involved aligning the mustard seeds along a scale and measuring the length covered by them. Then the students were to find out the average diameter for each one of the set of seeds. The students were asked to submit a written report on this task. In the report they were told to write the procedure, errors and precautions, assumptions and conclusions for the task. As a final task the students were to also plot a line graph for number of seeds versus the total length that they measured on the ruler. The format of the graphs can have significant impact on how the data is interpreted. Line graphs bring out the trends in the variables under question. If a particular trend is the most important information, then line graphs should be used (Shah, Mayer, & Hegarty, 1999).

Discussions on modelling the data

We tried to build a simple mathematical model from the data that would explain our measurements. Typical of the prevailing descriptions of the modelling process is that given by (Ackoff, 1956), as given in (Pinker, 1981). 1. Formulate the problem; 2. Construct a mathematical model to represent the system under study; 3. Derive a solution from the model; 4. Test the model and the solution derived from it.

The students did the task as a homework exercise and brought in the written reports. As a first step we asked what was the diameter of the mustard seed to each one of them. The answers varied, and it was through some probing on why the answers are varying, sometimes more than double, it emerged that there are in fact two different varieties of mustard seeds. The students had only either of the varieties at their homes, so had the data only for one of them. This provided us with an opportunity to discuss what differences size would mean for the mathematical model that was to be built.

During the discussion in the classroom it was asked to the students whether the values of the length that they have measured for different number of seeds have any mathematical relationship amongst them. First of all it was noted that as the number of seeds increase, the total measured length increases. So it was agreed upon that there is a direct proportion between the length measured for the seeds *L* and the number of seeds *n*. So that

$$L \propto n \qquad (1)$$

After the agreement of the two quantities being in direct proportion the discussion was taken further ahead by introducing the constant of proportionality (lets say *d*) and hence the mathematical relation between the two quantities *L*, and *n* can be written as

$$L = d\ )\ n \qquad (2)$$

At this point the students were reminded of the straight line equation

$$Y = m\ )\ X \qquad (3)$$

where *m* is the slope of the line. We then compared the two equations for similar terms. The total length *L* and the number of seeds *n* in equation (2) is analogous to the *Y* and the *X* values respectively in equation (3). The constant of proportionality *d* in equation (2) can be seen analogous to the slope *m* in equation (3). All this leads to the fact that equation (2) is indeed an equation for the straight line.

After showing that the mathematical relationship that is expressed by equation (2) is a straight line, it makes sense as to why we can draw a reasonable straight line passing through all the points. To make the understanding of the slope of the line and its meaning to the mathematical modelling, another exercise was done in the class. In this case the researcher collected the values of length from all the students, and put them on a spreadsheet for the class to see. The values were grouped into two parts, depending on the seeds. Then an average of these collected values was taken.

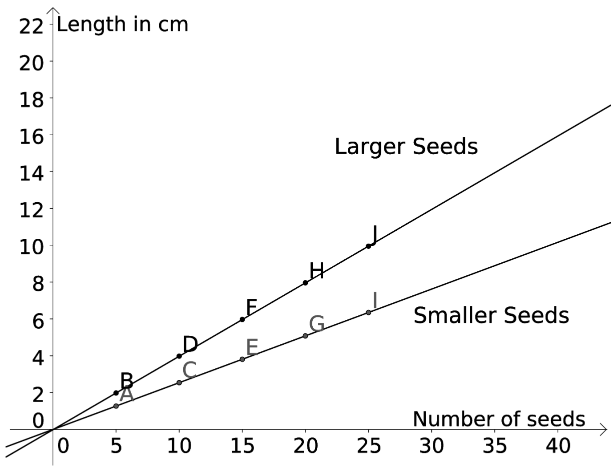

Figure 2: The graphs of lines for two different types of seeds drawn in GeoGebra from the average readings taken from students. The two lines differ in their slopes and this can be linked to the difference in the size of the seeds.

When all the data points for different number of seeds were collected, the researcher plotted these points and fitted a line through the points using GeoGebra [1], see Figure 2. As a result of this exercise, two distinct lines were plotted, corresponding to each type of seed. Discussion followed on what is the physical meaning of the slopes of the line in task at hand. In this case we have a concrete physical observation that the size (diameter) of the two types of seeds is different. On the other hand in the mathematical model, the slope of the lines are different. In this case we can relate the abstract change in the slope of the mathematical form to a concrete observation regarding the size of the mustard seed. This point was discussed at length in the class. Using GeoGebra in the classroom was also helpful to visualise how the lines would have looked like when the slope was different. For example if the seeds had an average diameter of 1 mm or 3 mm, where would the lines be with respect to the lines that were drawn.

The next step in case of mathematical modelling is predicting and testing the model. The questions that can be asked in this regard were can you predict the number of seeds that will form a given length or can you tell the

1 http://geogebra.org

length of given number of seeds. An interesting variation in this would be do this act collaboratively like a quiz. Some of the students may present their data and others are asked to find out about the missing quantities. And when there are discrepancies found in the expected and derived results, the discussions can be fruitful.

Student responses

Out of the 28 students only 2 students did not attempt to draw a graph or write any result. The rest of the students did attempt to draw the graph. In this section we discuss some important trends that we could gather.

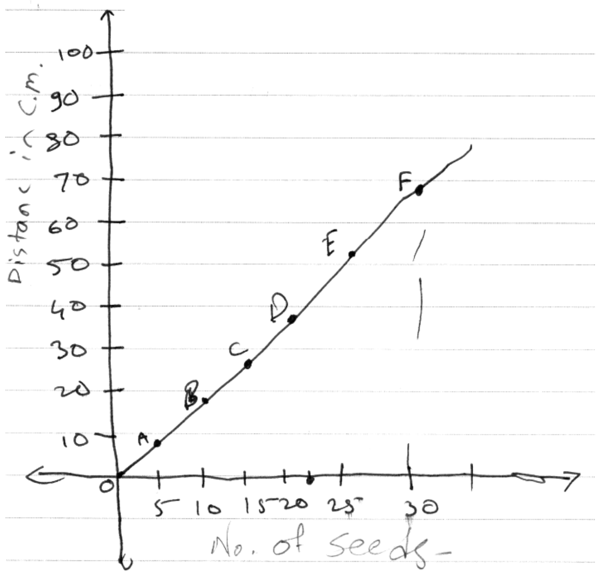

Figure 3. An example of graph from one of the students. Here the Y-axis is labelled as distance in cm, whereas it should be in mm and the points are approximately plotted. The scale on X-axis is not even, and none of the scales are mentioned.

The tables that were used to prepare for the graphs had data in the following format: Number of seeds - Length in mm/cm - Average length for 1 seed. Some of the students used calculators to get accuracy up to 4 decimals, this provided for opportunity to discuss the concept of least count, and number rounding off in the class. Most of the students did the measurements for 5, 10, 15, 20 and 25 seeds, though there were a few students who measured for up to 40 seeds.

Almost all of the students who drew the graph, could plot the data points correctly. Not all of them drew lines through the points that they had plotted. Some of the students drew the graph on the response sheet and not on the graph paper, example Figure 3. Only one student drew both bar graph as well as line graph. Most of the students choose scale of 5 seeds, per unit for X-axis and the scale for the Y-axis was seen to be variable. Many students choose the same scale as the actual readings, with 1 mm on the graph being equal to 1 mm of the actual measurements, example Figure 4. The students were not given specific instructions in choosing the scales, but they were asked to write the scales in the graphs that they drew. One of the students plotted the values of average diameter that was obtained from the measurements against the number of seeds.

During the classroom discussions the possible errors that would occur and ways to eliminate them were discussed. The students were to write about them in the reports. The most common reported error was of the alignment of the seeds with the measuring ruler. This we think was due to the fact that this error was readily perceptible by the students, and they could experience it while performing the task. One of the students actually glued the seeds on the paper to overcome this error! A few students drew diagram of the placement of the seeds with the ruler.

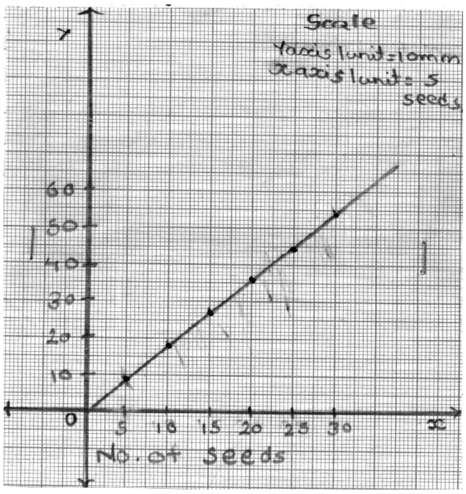

Figure 4. An example of graph from one of the students. Here the Y-axis has scale 1mm = 1mm and X-axis has scale of 5 seeds = 1 cm.

In a mathematical model, it is important to know the assumptions that we have for that model. It has been suggested that for students who are not accustomed to mathematical modelling, the teacher's main role is to clarify assumptions, and to inform students of the importance of assumptions (Seino, 2005). In our case the discussions in the class called for different assumptions that we had while making the measurements and while applying the mathematical model to the data at hand. The students in their responses listed out the assumptions, and sometimes mixed the assumptions with the precautions that they took while performing the task.

Some of the most commonly stated assumptions were [a] the seeds are spherical in shape, [b] the seeds are all of same size [c] they were aligned properly (in a line) while measurement, and [d] the number of seeds was counted properly. Though the two later ones can be said to be more of precautions than assumptions.

Only 8 students in their reports clearly wrote the final result. Many of the students, did only tabular calculations and did not proceed further. In conclusions of the report only three students wrote about the modelling part, and derived the linear equation for mathematical model. This was before the discussions in the class regarding the mathematical model.

Further work

The task of finding the diameter of the mustard can be seen as first step towards modelling of the real world based on data collected by the students themselves. This task though might appear as simple provides rich opportunities for linking modelling, measurement and graphicacy.

Though the task and the model were simple, not all the students could come close to the expected result, shows that the bridging and abstract mathematical knowledge to real world is not trivial. Therefore, it is vital to bring to the classroom such simple tasks, but rich enough to discuss several interrelated concepts in a close-to-life context. Other linear model tasks from real-(world?) such as measuring the thickness of paper, diameter of a thread can be done in continuation to this task. This would emphasise the power of mathematical modelling to the students that using the same general linear model, we can model for systems which are not similar to each other. For example when the points are plotted for all 3 experiments at once, we can understand the associated lengths (diameter/thickness) in terms of the slopes of the lines. Such examples will illustrate the enormous potential and universality of mathematical models to describe the real world. A few such experiments can act as a spring board to scientific modelling, and would help find the links between the models and the real world.

This is an ongoing work and the last part of the study, namely exploring the predictions and testing the model could not be completed in the small time frame that we had for the workshop. For testing the retention of the modelling task and that of predicting and testing the model we plan to conduct further tests and interviews with some of the selected students from the sample.

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Aspects of Learning Science in Inquiry and Traditional Classes: What Students' Diaries Reveal

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We present some preliminary results from an analysis of students' diaries of two batches of Grade 8 students undergoing inquiry and traditional science teaching respectively. The diary entries included a summary of what students had learned in class on that day and their opinions and feelings about the class. Analysis of students' first-person accounts of their learning experience and their notes taken during class was useful in two ways. Firstly, it brought out the differences in outcomes of the two interventions - both conceptual and affective. Secondly, this analysis brought out the significance and meaning of the learning experience for students in their own words, thus adding another dimension to the researchers' characterisation of the two teaching methods.

Introduction

Actively learning science involves hands-on experience and, equally importantly, making sense of that experience. Students' writing about their learning in the classroom has the potential to make explicit this attempt at sense making. It can give a glimpse of students' understanding, making clear what students have learned and exposing what they have not. It can also be a reflection of the teaching practice as well as the learning environment in the classroom (Baxter, Bass & Glaser, 2001; Ruiz-Primo, Li & Shavelson, 2002). In the present study, we analyse diary entries written by two batches of students undergoing science teaching through inquiry or in the traditional way and discuss how these two sets of diaries were different, qualitatively as well as quantitatively. These differences portray not only the differences in outcomes of the teaching modes but also a characterisation of these modes.

Literature review

Inquiry-oriented science teaching and its outcomes

The distinguishing feature of teaching through inquiry is that the teacher guides and supports students' thinking to help them to arrive at explanations based on evidence and argumentation (Cobern et al., 2010) rather than explaining concepts to students. Worldwide, reforms proposed in science education emphasize teaching science as inquiry yet it is not commonly practised in actual classrooms, and educational and political debates continue over its effectiveness (Anderson, 2002). Researchers in science education are addressing this problem in two ways. Firstly, studies have aimed to probe the efficacy of inquiry-oriented teaching (see review by Colburn, 2008). Secondly, acknowledging the difficulty of visualising inquiry in actual practice, attempts have been made to characterise the complex process of inquiry in the classroom (e.g. Roth, 1996). This study attempts to contribute to both these aspects.

Most of the studies evaluating inquiry teaching are based on content acquisition alone. Minner, Levy and Century (2010) express the need for analyses of the wide range of outcomes of inquiry teaching; in this study, we attempted to do this using open-ended responses from students in their diaries. Such studies on the practice and conceptions of inquiry often use either classroom observations by researchers or self-reports from teachers. By analysing diaries written by students, we provide another perspective, that of the students, through descriptions of their science learning experience in their own words.

Students' notebooks and reflective writing

Many researchers (e.g. Baxter, Bass & Glaser, 2001; Keys, Hand, Prain & Collins, 1999) advocate the use of writing in science notebooks to promote learning and as part of formative assessment. Ruiz-Primo, Li and Shavelson, 2002 and Minogue et al., 2010 explore the use of notebooks in conjunction with science investigations and how these notebooks can provide evidences of inquiry practised in the classroom. The focus of these studies has been on systematic accounts of science investigations. Encouraging a reflective component to students' writing (such as first-person, candid accounts as diary entries) can take students to deeper levels of reflection and help identify the significance and meaning of a given learning experience for the learner (Fink, 2003) as well as for researchers. There have been few studies on students' reflections on their learning experience and those are in the context of higher education (e.g. Wohlfarth et al., 2008). At the school level, (Hadzigeorgiou (2011) points out that optional diaries are useful to investigate students' involvement as well as content learning, using them in his study to provide evidence that invoking a sense of wonder while teaching science makes a positive contribution to learning as compared to teaching in a traditional way.

The study reported here differs from the ones described above in one or more of the following aspects: (a) maintaining a diary was not integral to either teaching or assessment and was optional (b) it was not a formal record during student investigations (c) entries were open-ended and reflective in nature and (d) they were used as a tool to explore and compare students' perceptions of learning in inquiry and traditional classes.

Theoretical framework

This study adopts a social constructivist perspective, which focuses on how personally meaningful knowledge is socially constructed through shared understandings (Vygotsky, 1978). According to this perspective, social interaction, especially with more experienced members (the teacher, in case of the classroom) provides children with ways of interpreting the world around them and thus students become "enculturated into ways of thinking that are common practice in that specific community" (Palmer, 2005). The learner diaries used in this study reflect students' efforts at making sense of events.

Methods

Setting and participants

In this paper, we report data from month-long classes we held with two batches of Grade 8 students from three schools in the vicinity of the researchers' institute. These schools, with English as the medium of instruction, followed the national curriculum in India. Students who volunteered to participate were randomly divided into two batches of 25 students each. Interaction with each batch was for two hours a day five times a week.

Two teachers from the research group individually taught one batch of students through inquiry (one of these teachers is an author of this report). Both the teachers had at least a Masters' degree in science but were not formally trained teachers. One of them had over 10 years of experience in research and in inquiry teaching. The other was a relative novice in inquiry but had taught at college level for two years; she was trained and got support for lesson planning from the expert teacher. Two teachers having a formal degree in teaching and a Masters' degree in science, taught the comparison batch. One of them had an experience of over four years in teaching at school while the other was a relative novice. Although they taught in the traditional way, they reported that they were able do fuller justice to their teaching in this program with no constraints of time or prescribed content of textbooks as in schools. They also had more time for preparation and put in considerable effort to make these classes more interactive than their normal classes, using questions and activities.

Teachers for both the batches had access to the same resource material and shared ideas for conducting activities. They had the same support in preparing for and conducting hands-on activities in class. However, the transaction of the material was entirely left to them. So essentially the difference between the two teaching modes was how students acquired a concept – whether it was explained to them or they grappled with them and developed them through exploration, with scaffolding by the teacher.

Two units, one on the concept of density and the other on fish were taught in both the classes. The unit on density essentially consisted of teaching (a) pre-requisite concepts of volume and mass and the inverse relation between these two, (a) density as the property of a substance and relative densities of different substances (b) floating and sinking of objects and (d) the Archimedes' principle. The unit on fish (with the larger aim of teaching classification) consisted of (a) similarities and differences between groups of fish, (b) fish as a taxonomic group (c) internal structure of fishes and (d) respiratory and circulatory systems of fish in comparison to human systems. The teachers in the comparison batch completed these units faster and taught additional units, one on electricity and magnetism and the other on biological cells in the remaining classes. In both groups, the teachers taught the units which fell in their area of training – physical science or biology.

Data sources and analysis

Students' diaries were the primary source of data for this study. Instructions, given by teachers to both the groups were essentially identical and asked students to note down what they had learned, how they felt about the class and anything interesting they came across in addition to class notes and homework. They were explicitly told that their writing was not going to be evaluated for grades and that they could be frank in their diary entries. Diary entries were encouraged but they were optional; however, at the end of some classes in the comparison batch one of the teachers gave students time to summarise in their diaries what they had just learned. Also, the teachers never read or discussed any of the diary entries in class, and accessed them only rarely. Additional details such as the exact instructions for writing diaries and the context of particular entries were obtained from video records of classes, field notes by observers and class summaries written by teachers.

Reflective text written on each day was counted as one diary entry. A bottom-up approach to coding of diary entries was adopted, that is, codes were generated from the data instead of pre-established codes based on theory. The data was coded by one of the authors, who was also an observer in the classes for both the batches. The emergent coding scheme and frequencies for each category are given in tables in the 'Results and Discussion' section. The conceptual correctness of the entries coded as 'what was learned' were analysed and discussed among the authors themselves first. The statements showing incorrect understanding from both the groups were collated, along with some correct statements, divided into three parts and evaluated by three independent researchers, each of whom looked at statements in the area of their content expertise. There were only a few differences between the authors and independent researchers; these differences were easily sorted out through discussion. Statements that were judged to be even partially correct were taken as correct.

Results and Discussion

Overview of results

Analysis of diary entries found qualitative as well as quantitative differences between the two groups of students. Students in the inquiry group wrote more number of entries (Table 1). There were differences, among the two groups, also on the aspects they wrote about (Table 2).

	Inquiry Group (n=20)	**Comparison Group (n=18)**
Number of students who made diary entries	19	18
Total number of diary entries for the group	284	126

Table 1. Quantitative comparison of diary entries of the two groups for 18 days of interactions

Comparison of science content learning

Comparison group: Most of the learning reflected in students' descriptions in this group was rule-based; often a recall of facts, definitions and laws and thus prone to errors (italicised).

Amount of matter in an object is called mass. When gravity pulls on the mass the object is said to have weight. The formula to find the weight of an object is kg x force (9.8 N)

> We learnt today that density of object = mass/volume. [Entry on the next day] I learnt more about density. We understood the formula to find density.

A large number of statements by the comparison group (47 vs 5 in inquiry) indicated a lack of conceptual clarity, and several instances of misunderstanding of the concepts.

> Objects which are not heavy will float, heavy objects will sink.
>
> We learned that the object which has *more mass and volume* has less density and the object which has less mass *and* volume has more density. So density is related to mass and volume.
>
> Density is the property of the matter... [later in the same entry] When there is a comparison between two objects of same material but of different sizes then, object with bigger size will have more density as it will have more weight because it is having [sic] more quantity of matter... Thus objects of *same material but of different volume show different density*.

These conceptual difficulties were not addressed by the traditional teacher despite being explicitly discussed during preparation. The inquiry teacher tackled them head-on for e.g. starting the unit with a question - does the amount of displaced water depend on the weight or volume of the object?Sometimes, as in the last instance above, incorrect statements were immediately preceded or followed by related correct statements indicating incoherence. Often conclusions of experiments were incorrect: “Carrot sinks [while bitter gourd didn't] *because*

Contents of diary entries	No. of instances in inquiry	No. of instances in traditional
Summarizing what was done in class (Total)	167	56
Mentioning the topics taught	67	29
Briefly stating what was done	49	17
Describing in detail what was done and how	24	4
Describing the lesson or activity as a question	27	6
Summarizing what was learned (Total)	56	73
Instances with conceptual clarity and coherence	51	18
Instances showing lack of conceptual clarity	5 (9%)	47 (64%)
Expression of what was felt (Total)	86	63
Positive	68	57*
Negative	6	4
Reflective notes on teaching-learning	10	2

* Out of these 22 were by one student

Table 2. Comparison of the content of diary entries of the two groups

it has more water molecules.” “I never knew that *salt has such high voltage* [in an experiment to compare conduction of electricity through plain and salt water]”.

Inquiry group: Students' summaries of what was learned were based mostly on experiments/ demonstrations and class discussions and a few on interesting facts -

> We had to find out the volume of the object from the water displaced. *As per my observation,* the volume depends on the size of the object, but in one case it was not true.
>
> Today teacher brought some objects, she dropped them in water and *through this experiment* we learned that there is no effect of air in making an object float or sink.
>
> I *noticed* the gills and the tail fins of the fishes. They were all different shaped and interesting.

In this group too, students arrived at incorrect conclusions, but in the initial stages of the unit.

> Then we were asked which [of the objects] displaced most water - the heavier object or the one which has more volume. We *had a discussion on it and came to the conclusion* that the thing which has more *height* will displace more water.
>
> Then teacher asked us a question - volume [of displaced water] depends upon what? *I think it depends upon its weight, size and mass.*

The description of learning is clearly different in the two groups. Students in the comparison group used formal, conventional statements whereas students in inquiry wrote in a more personalised way in their own words indicating better understanding and internalisation.

Comparison of students' affective responses to the teaching modes

The students in the inquiry group not only made higher number of optional entries but these were also more detailed as compared to the other group. This indicates their higher engagement with the science learning (Hadzigeorgiou, 2011). Additionally, they spontaneously made more notes in class and jotted down higher number of self-generated, spontaneous questions in their notebooks (Table 3). Out of the total of 35 questions, 22 were directly related to the content taught while the rest were general wonderment questions.

	No. of instances in inquiry	No. of instances in comparison
Spontaneous notes made in class	29	8
Attempt at an answer or question	15	4
Students' questions noted down spontaneously	22+13*	3

* One of the students asked 13 of the 35 questions

Table 3. Comparative data from students' notebooks indicating students' engagement levels

Aspects that students liked	No. of instances in inquiry	No. of instances in comparison
The class in general	15	28
Teacher or teaching	7	9
Experiments and demonstrations	24	14
Cognitive engagement/ high cognitive demand	12	1
Whole class discussion	4	0
Videos and slide shows	6	5

Table 4. Comparison of categories of positive responses

Students' comments about the classes are summarised in (Table 4). Students in inquiry reported that they enjoyed the classroom discussions: "It was great to get a chance to present our views in the debate.", "The question started hot debate. We said [sic] and *convinced the teacher about our answer*." While teachers in inquiry have noted that students enjoy intellectual challenges (Kawalkar & Vijapurkar, 2011), it is interesting that students have themselves reported their higher cognitive engagement in inquiry: "It was a good and tricky sum (problem) but we tried our best." "The crown battle had started... we were thinking how Archimedes had decided which crown is of gold and which is of silver." There was also an indication of students gaining a sense of self-efficacy in learning science: "Today we learned how to prove that an organism is a fish. It made us very excited. *I answered many questions*." "Today we did experiments and brought poems on fish. *I wrote a good poem."*

The negative responses of students in both batches were about some of the classes being "not so enjoyful [sic]" or even "boring". One student in inquiry complained that the same topic continued for three consecutive days and another said, "Today I did not enjoy as much as yesterday. We enjoyed the first session *but after that I was not understanding." S*uch awareness of their learning was not seen in the comparison group who wrote that the teacher explained very well yet displayed many conceptual errors in their entries on content.

Characterisation of the two modes of teaching implicit in diary entries

Comparison group: Diaries in this group show that teaching was different from traditional teaching in their schools in that there were many experiments and demonstrations, the class was kept interactive through questions, audio-visual material was used and that the teacher was perceived as being friendlier and explaining well: "In this class lots of activities were conducted and it was great fun on this day." "Our teacher showed us parts of fish and about fish on LCD screen. She also showed us real fishes." "The teacher asked us many questions... She explained to us very nicely." However, it is also evident through students' descriptions that though interactive and experiential, the teaching in the comparison group was through direct instruction. The experiments and demonstrations were verificatory and not investigative: "We learnt about density and *did some activities to clear the concept." "*We learnt that thicker the wire in size, the lesser the resistance it has and the longer the wire, the more the resistance it has. *We did an experiment to see the difference*."

Inquiry group: Students' entries in this group prominently reflect the focus on inquiry. Interestingly, many a times (Table 2) students wrote about a lesson or activity describing it as a question to be pursued (e.g. " Is that the seahorse is a fish? … we were asked to reason why it is fish..", "Why is 1gm of gold denser than 1gm of silver"). Learning in these classes was contingent upon observations and discussions: "We did an experiment *to find out if* the water fell out because of the mass or size?" "Teacher told us to guess the answers from what we had learnt before." It involved higher-level cognitive demands as reported by students. The teacher helped them meet these demands by being responsive to their ideas and difficulties and providing the necessary scaffolding (Kawalkar & Vijapurkar, 2011). It is reflected in students' entries: "Teacher asked some questions which were not easy...[Then] By this method (1000cc = 1 litre) it was easier to answer the questions and the concept was clear." "She asked a question which in the end almost all could answer." The essence of scientific inquiry in the classroom (US NRC, 1996) - that students critically engage in investigating questions, come up with explanations and evidences and communicate conclusions with convincing arguments – is reflected in the excerpts throughout this paper from diaries written by students in inquiry.

Concluding remarks

Apart from the differences in conceptual and affective aspects discussed earlier, what emerged was that students have internalised the inquiry approach to learning science - "we did this experiment to find out if...", "after much discussion we concluded that..." or that "we convinced the teacher of our answer". This is particularly significant because these aspects were not explicitly verbalised to students but were picked up by them from the way the classes were taught, activities presented, and classroom discussion and argument were used as an integral part of the teaching strategy. The epistemic difference in how students perceived learning science – whether it is "explained nicely" or it is "thinking how" and "to find out" was reflected in their diaries. We hope this study adds to the spectrum of outcomes of inquiry teaching, and lends support for adoption of this approach in the science classroom.

Acknowledgements

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Park City Mathematics Institute and Districts Partner to design Professional Development: Implementation and Evaluation

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The objective of the National Science Foundation (NSF) supported Mathematics/Science Partnership (MSP) was the transformation of mathematics teaching and learning in participating schools through a cohort of teacher-leaders. The Institute for Advanced Study (IAS)/ Park City Mathematics Institute (PCMI)'s Math-Science Partnership Project, PCMI and Districts Partner to Design Professional Development (PD3) focused on working with a critical mass of teachers within a school who attended a three week summer mathematics program, returning to their district to work with school personnel, university faculty in mathematics and education to bring about change in the teaching and learning of mathematics in that school.

Introduction

This paper showcases the findings from National Science Foundation (NSF) supported Mathematics/Science Partnership (MSP) categorized as a "Prototype Institute". The Institute for Advanced Study (IAS)/ Park City Mathematics Institute (PCMI)'s Math-Science Partnership Project, PCMI and Districts Partner to Design Professional Development (PD3) completed its final year on the grant in 2009. The ultimate objective of this grant was transformation of mathematics teaching and learning in PD3 schools through a cohort of teacher-leaders. IAS/PCMI has a 18-year history of providing a rich three week summer session with individual programs for high school teachers, college faculty, mathematics education researchers, undergraduate and graduate students, and research mathematicians and an emphasis on cross program interaction. PD3 focused on working with a critical mass of teachers within a school who attended the summer program, then returned to their schools and worked with a leadership team composed of school district personnel, university faculty in mathematics and education to bring about change in the teaching and learning of mathematics in that school.

Ball and Cohen (1999) have commented that in United States most of the money on professional development, "is spent on sessions and workshops that are often intellectually superficial, disconnected from deep issues of curriculum and learning , fragmented, and non-cumulative."(p3-4). The approach taken by PD3 was to immerse teachers from participating schools in an intense, sustained professional development experience at PCMI. Then throughout the year, the PD3 leadership team supported on-going professional development of this cohort of teacher leaders.

Literature Review

While some data have emerged on characteristics of effective professional development (e.g., Garet et al, 2001; Weiss et al, 2004), in general limited evidence of the impact of professional development exists with respect to high school teachers (Blank & de las Alas, 2009). In addition, the complex nature of professional development, first changing teachers and then observing the effect on student learning makes professional development difficult to study and as a consequence, much of the work is descriptive rather than quantitative (Sawchuk, 2010).

Recognizing this and building on what is known about quality professional development, PD^3 primarily focused on the first research area, improving teachers' practice, and to this end designed a sustained, coherent content-based professional development program that focuses on students, takes place during the school day and is part of a teacher's professional responsibilities (Wei et al, 2009). PD^3 blended summer experiences in an active and vibrant intellectual environment with academic year work on site in school communities. At the local level, project leaders developed formal protocols for guiding meetings, providing a structure and framework for the work, a factor that seems to emerge in professional development that affects teachers' practice (Gallimore et al, 2009).

Goals of PCMI

One of the goals of PCMI was to provide a national model program for mathematics-based career-long professional development for middle and secondary mathematics teachers through the PCMI summer Secondary School Teachers Program (SSTP). The three goals of the three-week residential SSTP program were: 1) deepening knowledge of mathematics which was operationalized through a 2 hour course meeting five times a week focused on investigating a central mathematical topic related to the PCMI mathematical theme , 2) reflecting on practice by devoting an hour a day each day of the three week session where teachers looked at open ended problems, student strategies, and their role in managing the discussion around the mathematics; and 3) being a resource for colleagues which was accomplished by working in collaborative groups that met for eight hours a week to develop an activity that would, if approved by reviewers, be shared as a resource on the SSTP web site. SSTP interaction with the other PCMI programs took place in a variety of ways. Participants interacted with graduates, undergraduates, and undergraduate faculty in pizza and problem solving sessions, attended cross program lectures by honored Mathematics Fellows and research mathematicians. The lectures were specifically geared to help the teachers understand the nuances of the annual PCMI mathematical theme. Two afternoon working groups function in connection with other PCMI activities: one that took part in an undergraduate faculty course related to the summer mathematical theme and the other, used cases to investigate teaching, observed and interacted with the laboratory teaching sessions conducted by a nationally renowned mathematics educator, Deborah Ball with rising fifth graders who attended her class at PCMI for two hours a day for six days. The laboratory class focused on the mathematical knowledge a teacher needed to interact with students around central mathematical themes, such as reasoning and proof. SSTP teachers in this working group learned to observe teaching, look for evidence as a lesson unfolded that learning is taking place, and to consider teaching behaviours that enabled this to happen.

A second goal was to effect, as 'proof-of-concept', systemic improvement of secondary mathematics teaching and learning in three diverse school districts through a transfer mechanism designed with district principals, math specialists and teachers. Secondary teachers from schools in three PD^3 districts representing diverse populations and regions of the country along with teachers selected from an applicant pool took part in the summer. During the academic year, PD^3 teachers' work was shaped by three subgoals: 1) Administrative buy in for the PCMI model so it became a template for professional development in the district; 2) Developing teacher leaders such that teachers co-designed and implemented professional development, interacted with university faculty and school and district leadership, to promote a school culture that values mathematics and teaching; 3) Teachers open classrooms by encouraging colleagues to observe and support each other's teaching, using research and data to make informed decisions.

Implementation of Program: Site level Professional Development

Each year of the project, 8 teachers from each site were selected to participate in the 3-week training institute at PCMI. In addition to the selected teachers, district curriculum specialists and partnering university faculty also participated in the training for one week. As part of the training activities, the participating teachers, along with their district personnel and faculty developed plans for on-going professional development at their sites which was to be instituted upon their return to the home campus.

At one of the PD^3 regional sites a rich and complex menu of professional development opportunities, including Video Club, sustained training for complex instruction, training in specific curriculum materials, and individual programs tailored to the needs of the school. The "PD3 staff" from the project-affiliated university and the public school system coordinated or led the professional development work. In addition, trainers from a professional training group helped with complex instruction and curriculum materials training.

Video Club, a monthly meeting open to all teachers from partnership high schools where participants who watched and discussed a video clip from one of the participant's classrooms. Facilitators led the participants through the relevant part of the mathematical activity from the clip and led a discussion about the problem, how it fit in with larger topics in mathematics, and ways students might get confused. The goal of this first discussion was to help teachers deepen their understanding of the mathematical content while developing their knowledge of students' mathematical learning. Afterwards, teachers viewed the clip from the tape with the question: What can we tell about what these students understand about the mathematics? The goal of the viewing and discussion was to help teachers develop their eyes and ears for the kind of formative assessment that informs instructional decision-making.

At the second site, located in a rural part of a large southern state, a unique model for interacting with a school district through ITV was implemented. This model was used to build a mathematical learning community in the public schools that also informed our district wide professional development programs for in-service teachers.

The goal was to promote a better understanding of the problems faced by teachers in the classroom, and how these could be addressed in partnership with a university even through long distance communication. This also allowed the partnering university's faculty to have a better understanding of the role of teachers as leaders in professional development, and how mathematical learning communities of teachers could guide and sustain professional development in the district.

Each session focused on three key questions:

1. What mathematics topic are you currently teaching?
2. What about the topic difficult for students?
3. How can this difficulty be addressed?

These questions were designed to promote discussion about issues of teaching and learning mathematics as a group and find solutions together. Faculty took the opportunity to share relevant research findings. Teachers take the opportunity to ask for resources often related to improving student achievement. Besides teachers and faculty, the principal and district administrator took part in the conversation.

At the third site, the Japanese practice of Lesson Study was implemented.

Six Lesson Study teams were formed. The teams included teachers from a high school and five middle schools (Chaparral, Gadsden, Riverside[1] and Santa Teresa). The program was initiated with the teaming attended a Lesson Study conference where they were introduced to the concepts and procedures involved with developing lesson study plans and implementing them in the classroom to facilitate students' understanding of mathematical concepts. The conference was facilitated by two international leaders in the practice of Lesson Study-Dr. Akihiko Takahashi and Tad Watanabe. During the conference participants observed a lesson study and learned how to provide constructive feedback to Lesson Study presenters. The teams met formally six times during the year (three times for Lesson Study Conferences with Dr. Takahashi and three times for public presentations). After the training, individual Lesson Study teams met on their own to develop the lessons that were presented at the Lesson Study workshops. Following the initial introductory session, the Lesson Study experts visited the twice as part of the year-long learning experience and provided critiques of the presentations, encouragement for further development and guidance for improving the experience for students. As part of Lesson Study, teams of teachers lead public lessons which are observed by other lesson study participants, teachers, and occasionally school administrators. These public lessons were video taped for presentation and subsequent discussion.

Evaluation

To assess the impact of the project and to ensure fidelity of the program implementation, the evaluation team used a variety of data collection methods including: paper/pencil and on-line surveys, site visits which included interviews of district and school leadership and PCMI participating and non-participating teachers, participant observations of professional development activities, and student achievement data from state-level assessments.

PCMI Experience

An exit survey indicated that a majority of teachers who participated in the PCMI institute found the experiences very valuable for gaining ideas for classroom activities, interacting with broader mathematics community, learning new classroom strategies and collaborating with colleagues. Follow-up interviews with teachers indicated that a majority of the teachers had a positive reaction to the morning sessions on mathematics problem solving and the "Reflection on Practice" sessions. They reported "buying into the PCMI methodology," feeling "refreshed and brimming with ideas" and gaining valuable insights in how to change, adjust and adapt lessons in support of student learning.

Some teachers reported that their PCMI experience would have been more rewarding if there were other participating teachers from their school. First time participants found it an "intense experience." Returning teachers, especially those who had attended three or more summer institutes reported that future participation at PCMI would be in leadership roles (e.g., table leaders).

The goals for the on-going professional development/teacher-leadership activities in their schools following the PCMI Summer Institute was to: 1) **Administrative Endorsement:** the PCMI model becomes a template for professional development in the district, 2) **Teachers Lead:** Teachers co-design and implement professional development, interact with University faculty and School and District leadership, to promote a school culture

1 Riverside Middle School was not a participating school.

that value mathematics and teaching and 3) **Teachers Open Doors:** Teachers observe and support each others' teaching. Teachers use research and data to make informed decisions.

The evaluation team developed an interaction model for PD^3 (Figure 1). This model provided an analytic framework for evaluating project outcomes.

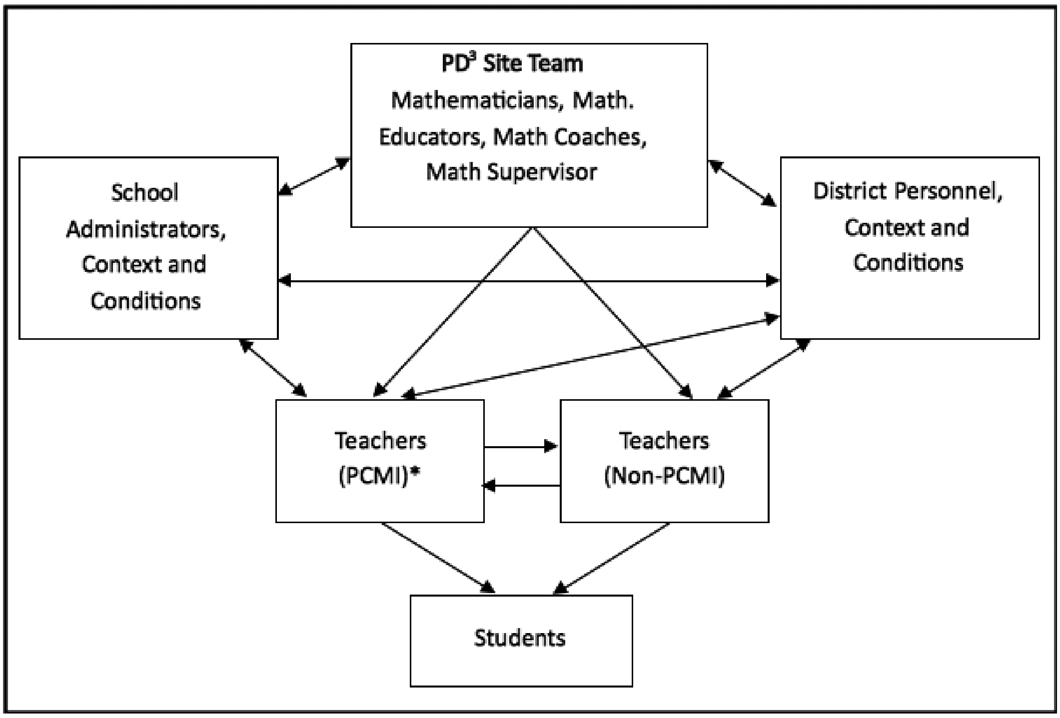


Figure 1. Interaction Model for PD^3

Description of the Interaction Model

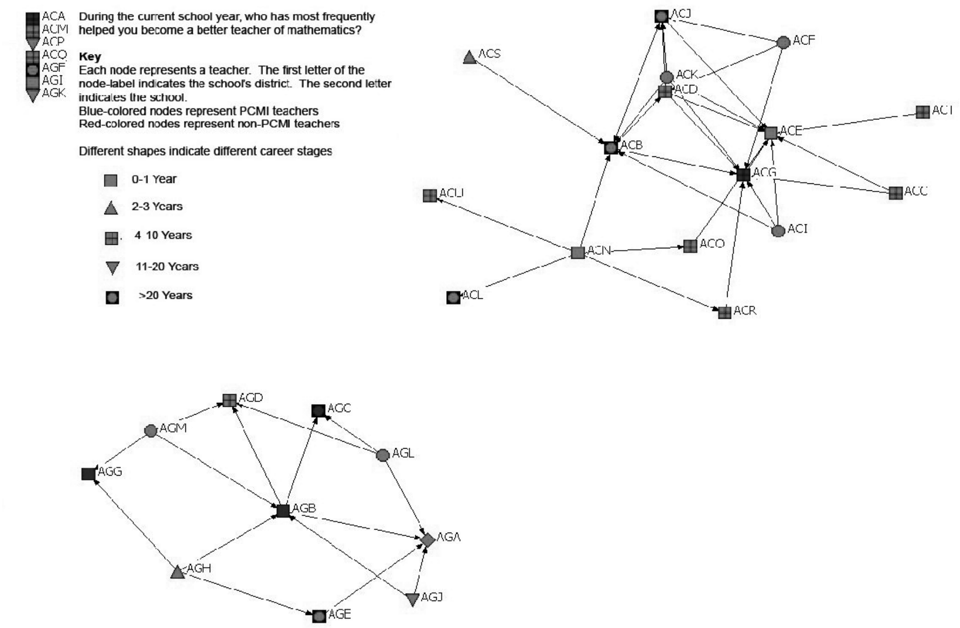
The conceptualized PD3 (PCMI and Districts Partner to Design Professional Development) model suggests bidirectional relationships between the PD3 team, district and school level personnel, teachers who participated in the PCMI program, and non-PCMI teachers. By forging a collaborative relationship with each of the stakeholders in the PD3 model, the project envisioned that each partnering district would gain administrative endorsement of the professional development model, and create strong teacher leaders who made data-based decisions about their practice and mentored other teachers. In doing so, the intended outcome was to enhance student achievement (the attained curriculum).

Data to support the Interaction Model and Evaluation Goals

To determine if the interaction model best represents the implementation of the project goals, site specific data were obtained regarding: a) nature and frequency of communication and interaction among the PD3 team, district and school level personnel, PCMI and Non-PCMI teachers and students, b) level and scope of teacher participation in professional development activities and c) evidence regarding changes in teaching practices linked to PD3 professional development experiences.

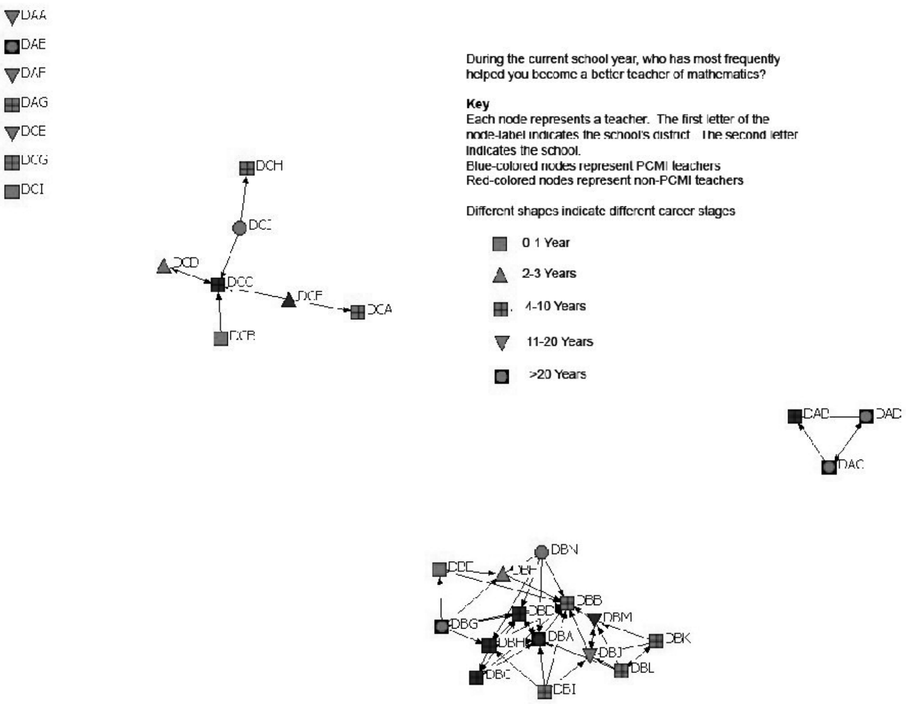
In order to understand how new information moved and diffused in schools; we needed to know who talks to whom about this new information. To understand the diffusion of new information in schools, Social Network methodology was employed (Frank, Zhao, & Borman 2004) and teachers nominated: a) closest colleague, b) person/s who helped you become a *better teacher of mathematics*; you can talk to about *new ideas related to teaching mathematics*; or the *mathematics curriculum*.

Based on teacher responses social network depictions of directionality of influence could be determined. Depictions of the networking patterns for the nominations of 'person/s who most helped you become a better teacher of mathematics' for two of the participating sites are presented in figures 2 and 3. These depictions allowed us to describe the extent to which teacher leadership was being developed at the sites and to determine intra and inter-site contextual factors that moderated emergence of teacher leadership.



Nominating Criteria: During the current year, who has more frequently helped you become a better teacher of mathematics?

Figure 2. Nomination Patterns at Site A.



Nominating Criteria: During the current year, who has more frequently helped you become a better teacher of mathematics?

Figure 3. Nomination Patterns at Site B.

Conclusion/Findings

Evidence suggests that consistent and sustained project support coupled with a stable composition of the PD^3 leadership team has contributed to the successful outcomes at one high school in one site. Evidence also suggests that strong district level leadership and vision coupled with project support offer great promise of successful outcomes at the participating middle schools in another school district at a second site.

Project related activities at two of the sites, especially as they related to the goal of teachers opening doors make an important contribution to our understanding of factors that make profession development effective. Both sites encouraged teachers to make their teaching public and enhance the teaching-learning process through collaborative planning.

Evidence gathered suggests that consistent and sustained project support coupled with a stable composition of the PD^3 leadership team has contributed to the successful outcomes at the high school referenced above. Evidence also suggests that strong district level leadership and vision together with project support offered great promise of successful outcomes at the participating middle schools in the second site.

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Introducing Engineering and Technology Education in Primary Schools

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The action research study, aimed at developing interest and understanding among primary school students in engineering and technology. Data were collected by administering a modified version of a pre-validated questionnaire 'Engineering is Elementary' (EIE) twice to 340 upper primary school students in a three phase study. In the first phase students' existing understanding about 'What Engineers Do?' and 'What is Technology?" were explored. In the second phase a lecture explaining the relationship between Science, Technology and Engineering was delivered followed by three engineering related student activities. In the third phase the EIE was readministered and significant differences in student understanding were identified in recognition of the items in the EIE suggesting that an intervention programme could play key role in creating students interest in engineering and Technology.

Introduction

Despite massive advances in science, few citizens worldwide are technologically literate, largely because technology and engineering are seldom taught in schools (Lachapelle & Cunningham, 2007). Just as it is important to begin science instruction in primary school by building on children's curiosity about the natural world, it is also important to begin engineering instruction in primary school by building on children's natural inclination to design, build and take things apart (Cunningham & Hester, 2007). At the heart of engineering is an understanding of the engineering design process – a highly flexible method of solving problems. It is essential that young people's interest in science, technology and engineering is stimulated and maintained throughout their schooling so that students continue with studies in these fields at the university level in order to address the skills shortage (MCEETYA, 2006). A community with an understanding of the nature of science and scientific inquiry will be better equipped to participate in an increasingly scientific and technological world (Williams, 2001). Opening young minds to the wonders of the natural world, stimulating curiosity and creative thinking, and starting that journey towards scientific and technological literacy, requires a strong and effective primary school engineering programme.

Science through engineering can be seen in every aspect of the built environment and it is essential to Australia's prosperity, lifestyle and global competitiveness. As Australia moves into the knowledge-based economy, it is vital for Australia's future development that the number of engineering graduates increases. To increase the number of engineers, children must develop an interest in science, engineering and technology throughout their school lives. Accordingly, cultural and curriculum changes within the schooling system need to occur. In Australia while the numbers of students completing Year 12 have increased, the proportion of students interested in studying chemistry, physics and advanced mathematics has declined, and initiatives to address this decline need to be implemented as a matter of urgency (Wogan, 2011).

Research Questions

The overarching aim of this project was to develop interest and understanding through improved learning environments among primary school students in engineering and technology (E & T) as potential career choices in order to redress the problem of insufficient numbers in the pool of locally-trained professionals in these fields. Further, the project aimed at developing the engineering and technology literacy of primary school students and teachers. The objectives of this study are:

- To investigate what activities primary school students classify as being E & T.
- To develop and validate an instrument to assess the primary school students' learning environment and their understanding and interest in E & T.
- To assess the effectiveness of the implemented E & T lessons in terms of the quality of the classroom learning environment and student understanding and interest in E & T.

Theoretical Framework(s)

Learning Environment Research

The study drew upon and contributed to the burgeoning field of learning environments (Fraser, 2007). Contemporary research on school environments partly owes it's inspiration to Lewin's (1936) seminal work in non-educational settings, which recognised that both the environment and its interaction with the characteristics of the individual are potent determinants of human behaviour. Since then, the notion of person-environment fit has been elucidated in education by Stern (1970), and Walberg (1981) has proposed a model of educational productivity in which the educational environment is one of nine determinants of student learning. Over the last four decades, learning environment research has become a firmly established form of research on teaching and learning (Fisher & Khine, 2006).

A hallmark of the field of learning environments is the existence of a variety of economical, robust and extensively validated questionnaires that measure different psychosocial dimensions of the classroom. These instruments are used to investigate the learning environment more closely from the perspective of the students who make up a classroom rather than from the perspective of trained observers or teachers.

One of the most promising applications of classroom environment assessments is their use as process criteria of effectiveness in evaluating educational programmes. For example, when Martin-Dunlop and Fraser (2008) used learning environment criteria in evaluating an innovative science course for prospective American primary teachers, students reported very large gains in classroom open-endedness and material environment between the beginning and end of the course. Similarly, when Nix, Fraser and Ledbetter (2005) evaluated the impact of an innovative teacher development programme based on the Integrated Science Learning Environment (ISLE) model in school classrooms, students whose science teachers had attended the ISLE program perceived more positive learning environments in their classrooms relative to the classrooms of other science and non-science teachers in the same schools. In the proposed study, we also will use learning environment criteria in evaluating the effectiveness of the implemented engineering programme.

Engineering and Technology (E&T) Education

Traditionally engineering has been known as a formal post-secondary discipline and engineering education has focussed on improving the teaching and learning of engineering at the tertiary level (Bagiati & Evangelou, 2011). Despite huge advances in science, few citizens worldwide are technologically literate, largely because E&T is seldom taught in schools (Lachapelle & Cunningham, 2007). Just as it is important to begin science instruction in primary school by building on children's curiosity about the natural world, it is recognised internationally that it is equally important to begin E&T education in primary school by building on children's natural inclination to design, build and take things apart (Andrews & Clark, 2011; Cunningham & Hester, 2007). In Australia, the problems of declining numbers in student preferences in E&T stem from the lack of engagement with science and technology in primary schools (Australian National Engineering Taskforce, 2010). It is highly desirable that young people's interest in both science and E&T is stimulated and maintained throughout schooling so that students choose to continue with studies in these fields at the university level in order to redress the skills shortage (MCEETYA, 2006; Petroski, 2003).

Solomonidou and Tassios (2007) found that Greek children aged 9–12 years tend to think of technology as anything "modern" and have difficulty in thinking about technologies as having any history. Burns (1994) found that New Zealand children aged 12–13 years have ill-defined concepts of technology, whereas DeVries (1996) found that young adolescent children in the Netherlands view technology as a collection of products, particularly "high-tech" products, and show no awareness of technological processes. Lachapelle and Cunningham (2007) found that primary-school children in the USA tend to think of technology as anything modern or anything powered by electricity and think of engineers as people who repair things such as cars or who construct buildings and bridges. The compelling evidence above motivated us to propose this research programme.

High-quality teaching of science in Australian primary schools is a national priority in order to develop citizens who are scientifically literate, can contribute to the social and economic well-being of Australia, and achieve their own potential (Goodrum & Rennie, 2007). Opening young minds to the wonders of the natural world, stimulating curiosity and creative thinking, and starting that journey towards scientific and technological literacy require a strong and effective primary-school E&T programme that promotes positive learning environments and student interest and understanding in E&T.

Methodology

The initial study involved 340 students from 15 primary classrooms in five schools in years 4, 5 and 6. A survey instrument by Lachapelle and Cunningham (2007) was modified and implemented to assess these students' understanding and interest in E & T. After the survey a lesson defining engineering and the importance of Science, Engineering and Technology was delivered to these classes by the first author who is an engineer by training.

In addition at least one engineering topic (two to three lessons), chosen by the class teachers was taught in these classes. The topics taught were in the area of (i) oil spill solutions (ii) electricity (iii) earthquakes (iv) natural and processed materials (v) energy and change and (vi) human biology. Researchers used lesson plans from Tryengineering (www.tryengineering.org) as a guideline and modified them to fit local needs. Teachers were given the lesson plans, materials and any other support they needed for these lessons. These lessons were observed by at least one researcher. A post-test survey was administered to these students to find any changes in understanding and interest in E & T. Table 1 represents the demographic information about the participating students in the study.

School	Student No	Cohort (%)
1	67	19.7
2	77	22.6
3	69	20.3
4	54	15.9
5	73	21.5

Year	Student No	Cohort (%)
4	126	37.1
5	120	35.3
6	94	27.6

Parent engineer	Student No	Cohort (%)
Yes	33	9.7
No	307	90.3

Gender	Student No	Cohort (%)
Boys	147	43.2
Girls	193	56.8

Table 1. Demographic information about the sample

Findings

Validation

The validity and reliability information of the instrument used in this study was determined by the degree to which items in the same scale measure the same aspect of interest and understanding of E & T, a measure of internal consistency, the Cronbach alpha reliability coefficient (Cronbach, 1951) was used. The alpha reliability of 0.71 was obtained for the scales of 'What Engineers Do' and 0.63 for the scale of 'What is Technology'. Both the scale reliabilities are above 0.5 making the instrument reliable for use.

Perception of Engineering and Technology

The survey probed children's perception of engineering and technology, asking them 'What does an engineer do?' and 'What is technology?', to draw examples of what an engineer does and what is technology, and to describe their pictures in words. The results indicated that students generally had a poor idea about the type of work engineers do while more than 60% students had sound understanding about technology. Very few students wanted to take up engineering related careers, however, there was an increase in student career aspirations as well as understanding of engineering and technology in the post-test results. Details of the results can be seen in Table 2.

In order to more systematically probe student's perceptions of E & T, the questionnaire included both captioned images of working people from which the students had to choose those that showed what an engineer would be expected to do at work, and other captioned images of items that may or may not represent technology while asking students, "What is technology?" In both tests the students showed a significant shift towards selection of correct responses between the pre-test and post-test results (please see Tables 3 and 4). As part of our evaluation of the E & T teaching, we examined the pre-test/post-test changes in students' perceptions that occurred during the instruction. Each wrong answer was marked as zero and right as one. The magnitude of each pre-test/post-test difference is described in Tables 3 and 4, in terms of effect size (i.e. the number of standard deviations), whereas a t-test for paired samples was used to determine the statistical significance of this difference.

	Pre-test		**Post-test**
	Student No	**Percentage**	**Student No**
Work aspiration (What would you like to be when you grow up?)			
Engineering	26	7.6	35
Non engineering	314	92.4	260
No response			45
Engineering brainstorm (What does an engineer do?)			
No idea	9	2.6	2
Poor idea	170	50	10
Moderate idea	65	19.1	96
Sound idea	96	28.2	232
Technology brainstorm (What is technology?)			
No idea	11	3.2	3
Poor idea	20	5.9	4
Moderate idea	104	30.6	32
Sound idea	205	60.3	301

Table 2. Student work aspirations and understanding of Engineering and Technology

Item	**Item mean**		**Item SD**		**Differences**
	Pre-test	**Post-test**	**Pre-test**	**Post-test**	**Effect size**
Design circuits	0.69	0.87	0.46	0.34	0.44
Make better food	0.02	0.09	0.13	0.29	0.32
Design machines	0.75	0.96	0.43	0.21	0.68
Better farming	0.15	0.37	0.35	0.48	0.52
Design better phones	0.46	0.82	0.49	0.38	0.82
Design MRI	0.44	0.78	0.49	0.41	0.77
Design tablets	0.04	0.54	0.21	0.51	1.32
Protect coastline	0.13	0.32	0.34	0.47	0.47
Work as a team	0.57	0.83	0.49	0.38	0.59
Make smaller recorders	0.31	0.67	0.46	0.47	0.77
Design bridges	0.56	0.90	0.49	0.30	0.83

Item	Item mean		Item SD		Differences
Design space shutters	0.49	0.79	0.50	0.41	0.66
Work as electrician	0.39	0.35	0.49	0.48	0.08
Build houses	0.59	0.48	0.49	0.50	0.22
Drive machines	0.69	0.73	0.46	0.44	0.08
Repair machines	0.20	0.27	0.40	0.45	0.16

Table 3. Item Mean and Standard Deviation for Pre-Post tests in Students' Perceptions on the items in the Engineering Questionnaire

Effect Size, in terms of the differences in means divided by the pooled standard deviation ranged between 0.08 to 1.32 standard deviations for the engineering test and 0.06 to 0.98 standard deviations for the technology test. The effect sizes for the engineering questions were larger for most scales.

The engineering test recorded statistically significant changes in all items pre-test/post-test differences except for the item of 'work as electrician' and 'drive machine'. Similarly only three items demonstrated insignificant changes in pre-test/post-test differences in the technology test.

Item	Item mean		Item SD		Differences
	Pre-test	Post-test	Pre-test	Post-test	Effect size
TV	0.96	0.98	0.19	0.13	0.12
Train	0.76	0.89	0.43	0.65	0.23
Running shoes	0.09	0.49	0.29	0.50	0.98
Telephone	0.94	0.97	0.24	0.17	0.14
Tea cup	0.05	0.12	0.21	0.33	0.25
Manufacturing plant	0.62	0.78	0.49	0.41	0.35
Refinery	0.54	0.75	0.49	0.43	0.45
Computer	0.97	0.98	0.16	0.13	0.06
Bicycle	0.14	0.34	0.35	0.47	0.48
Bridge	0.13	0.42	0.34	0.49	0.69
Genetics (artificial arm)	0.31	0.47	0.46	0.50	0.33
Spaceship	0.83	0.90	0.37	0.31	0.20
Tree	0.98	0.96	0.13	0.19	0.12
Bird	0.99	0.97	0.12	0.16	0.14
Lightening	0.76	0.64	0.43	0.48	0.26
Ecosystem	0.89	0.80	0.32	0.39	0.25

Table 4. Item Mean and Standard Deviation for Pre-Post test in Students' Perceptions on the items in the Technology Questionnaire

Qualitative data

After running E & T lessons informal interviews were conducted with participating teachers and students. Denzin and Lincolin, (1994) bricolage method influenced the research team while interpreting the information, which was collected using a variety of research methods. This approach enabled the team to draw on a variety of paradigms for their interpretation in a bid to explain the cultural, factors that could contribute towards the student understanding and interest in E & T. Qualitative data further strengthened our claim. Teachers recognised the need for E & T education and longed for support. Both students and teachers felt that it is imperative for a safe future for Australia that E & T education should be imparted to primary students. The main points, which emerged from the teacher and student interviews, are:

- Expert Support
- Resources-Material to Teach, Resource Book and Resources for student site visits

Conclusions

The results of this pilot study have demonstrated that at the time of the pre-test students had a fair understanding of what technology meant and generally very poor understanding of what engineers do. Students and teachers enjoyed the E & T lessons and statistically significant differences were recorded in students understanding in the post-test. Further work is continuing to incorporate research, evaluation and assessment into all aspects of curriculum design and testing from its inception. Our research questions, assessment instruments and curriculum continue to evolve.

Recommendations and future research plans

There will be a continuing effort to run similar projects for primary and secondary school students. This effort needs to be strengthened by professional development of teachers and a unit on engineering education in teacher education programmes.

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Co-Teaching and Co-Generative Dialogue for Transforming Teacher Interpersonal Behaviour in Secondary Schools

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The paper reports on part of a longitudinal study which aimed to investigate the effectiveness of co-teaching and co-generative dialogue in the science learning and teaching in lower secondary science classes. In this study, co-teaching and co-generative dialogue are applied for transforming teacher interpersonal behaviours. This multiple case studies research was conducted in three different secondary schools. Interviews, students' reflective journals, and Questionnaire on Teacher Interaction (QTI) were used to develop in-depth understanding of the participants. The results show that co-teaching and co-generative dialogue helped in transforming teacher interpersonal behaviours after embedding it in classroom practices. It also had implications on developing teachers' pedagogical praxis, transforming teaching behaviour, and improving students' engagement, achievement, and behaviour.

Introduction

Teacher plays an important role in ensuring good quality of education and in developing good quality of human resources. Many researches, as reflected by literature, demonstrate the important roles of teachers in educational processes. According to Fullan (1991), the educational change heavily depends on teachers' thinking and action which is a complex process. Moreover, the teacher also plays a significant role as "a moral agent who transmits the values overtly and covertly" (Beyer, as cited in Marsh, 1996). As a result, it is important to ensure the quality of teacher and teaching. In this study, the science teachers, the researcher, and the students were engaged in the process of co-teaching and co-generative dialogue. In this practice, three students each fortnight from each class were identified to provide reflections on their teacher's practices. The researchers were included in the conversation and they made teachers aware of practices of which these teachers could be unaware. The results showed not only the transforming of teacher interpersonal behaviour, but also quality of teaching practices and student learning.

Questionnaire on Teacher Interaction (QTI)

One of the learning environment questionnaires namely *Questionnaire on Teacher Interaction* (QTI), was used in this study for guiding teacher-student interactions transformation. Wubbels, Creton, and Holvast (1988) investigated teacher behaviour in classrooms from a systems perspective, adapting a theory on communication processes developed by Watzlawick, Beavin, and Jackson (1967). Within the systems perspective on communication, it is assumed that the behaviours of participants influence each other mutually. The behaviour of the teacher is influenced by the behaviour of the students and this in turn influences student behaviour. Circular communication processes develop which not only influence behaviour, but determine behaviour as well. With the systems perspective in mind, Wubbels, Creton, and Hooymayers (1985) in The Netherlands extrapolated the seminal interpersonal behaviour research of Leary (1957) to develop an instrument, the *Questionnaire on Teacher Interaction* (QTI), to gather students' perceptions of their interactions with their teacher (Wubbels & Levy, 1993). The QTI assesses eight dimensions of teacher behaviour: leadership, helping/friendly, understanding, student freedom, uncertain, dissatisfied, admonishing and strict. These dimensions provide a comprehensive description of teachers' interactions with their students.

The Dutch version of the QTI was translated into English and modified for use in Australian secondary schools. The Australian version of the QTI has been used in studies involving secondary science classes (Fisher, Fraser, & Wubbels, 1993; Fisher, Henderson, & Fraser, 1995; Fisher & Rickards, 1998). These studies strongly supported the validity and potential usefulness of the QTI within the Australian context, and suggested the desirability of conducting further and more comprehensive research involving the QTI. Generally, higher cognitive achievements are positively associated with leadership, helping/friendly and understanding teacher behaviours. Conversely, admonishing, dissatisfied and uncertain teacher behaviours are negatively associated with students' cognitive achievements (Fisher & Rickards, 1998; Koul & Fisher, 2003; Wubbels & Levy, 1993). In terms of the instruction and achievement, the study focuses on both these areas in an enhanced manner, where additional emphasis is given to teacher-student interactions. Additionally, the present study extends the use of the QTI into middle schools, an area of formal schooling receiving considerable attention nationally and internationally (Koul & Fisher, 2005).

Scale	Description	Item
Leadership [DC]	Extent to which teacher provides leadership to class and holds student attention.	This teacher explains things clearly.
Helping/Friendly [CD]	Extent to which teacher is friendly and helpful towards students.	This teacher is friendly.
Understanding [CS]	Extent to which teacher shows understanding/concern/care to students.	If we don't agree with this teacher, we can talk about it.
Student Responsibility/ Freedom [SC]	Extent to which students are given opportunities to assume responsibilities for their own activities.	We can influence this teacher.
Uncertain [SO]	Extent to which teacher exhibits her/his uncertainty.	It is easy to make a fool out of this teacher.
Dissatisfied [OS]	Extent to which teacher shows unhappiness/dissatisfaction with student.	This teacher thinks that we don't know anything.
Admonishing [OD]	Extent to which teacher shows anger/temper/impatient in class.	The teacher is impatient.
Strict [DO]	Extent to which teacher is strict with and demanding of students.	We are afraid of this teacher.

Table 1. Description and Examples Items for each Scale in the QTI

Based on Leary's model, Wubbels and Levy (1993) provides the map of teachers' behaviour with the proximity dimension (Cooperation dan Opposition) and Influence dimension (Dominance-Submission) from the each scales of QTI. Therefore, in this research, the QTI provided the big picture of teaching behaviour and teacher-student interactions. Then the multiple methods of observations, interview, and students' reflective journals were used to provide the integrated picture of the research.

Co-Teaching and Co-Generative Dialogue

Tobin (2006) described co-teaching occurring, when two or more persons collaborate, to teach a group of students. The presence of multiple teachers provides a greater array of dynamic structures than is possible when only one teacher is present. Accordingly, students in a class experience an expanded agency and associated opportunities for learning and creating new identities. A higher incidence of teaching in co-taught classrooms is not only experienced by students, but also by the teachers who can appropriate the enacted teaching of others to expand their own repertoire of teaching practices. Co-teaching and co-generative dialogue has been implemented in this research to improve the science teachers' pedagogical practices. Co-teaching as co-learning provides opportunity for teachers to reflect on their practices (Roth, 2005). Students also get benefits from modification of their learning. Through co-generative dialogue, students have opportunities to participate actively on improving their learning and their teacher pedagogical practices. According to Stith and Roth (2008), involving students in co-generative dialogue, will help them to engage and contribute to their learning which will lead to the classroom transformation. Co-teaching and co-generative dialogue have been used for teacher evaluation (Roth & Tobin, 2001), for classroom praxis (Martin, 2006; Roth, Tobin, & Zimmermahn, 2002), for transforming classroom culture (Lehner, 2007), and for transforming teachers' beliefs and practices (Carambo & Stickney, 2009). In addition, co-teaching and co-generative dialogue provides opportunities for the teachers for sustaining the transformation process (Martin, 2006).

In this research, the science teachers, the researcher, and the students were engaged in the process of dialogue, collaboration, and reflections. The science teachers' incorporated the feedback from students to improve their pedagogical practices and enhance student learning. In this practice, two or three students from each class were identified to provide reflections on their teacher's practices, such as 'How could I teach better so that my students like my lessons?' The value of getting teachers and students together to discuss their shared experiences was highly appreciated (Tobin, 2006). What can be improved, what is working well, what is frustrating, and what is most enjoyable, are topics that have been discussed? The use of this conversational format allows teachers to get beyond lists of things that need improvement and to delve more deeply into the nature of teaching. Interactions allowed deeper probing of classroom life and a meeting of the minds. The researchers were included in the conversation and they made teachers aware of practices of which they could be unaware. Hence, discussions lead to increased awareness, the creation of language and associated images to represent salient features of teaching and learning, identification of changes that would likely improve the quality of teaching practices as well as learning environments and as a consequential improvement in student learning. Therefore, in this study, co-teaching/co-generative dialogue approach was undertaken for transforming teaching pedagogical practices and teacher evaluation.

Methods

The study implemented multiple case studies in three year-9 science classrooms from three schools with different culture and characteristics. Co-teaching and co-generative dialogue was developed and implemented for three years to transform teacher interpersonal behaviour and teacher-students interactions. Multiple research methods (observations, *Questionnaire on Teacher Interaction* (QTI), interviews, and reflective journals) are manifold ways to investigate the improvement in teaching practices.

The Participants

The study involved co-teaching with three science teachers and their students in three participating schools. This paper focuses on the second year of study, when the students were in year-9. Below are the brief descriptions of the participants at the time of the study.

- **School 1** is a public school with a good academic reputation and achievement. This school has outstanding science teaching learning resources. The researchers worked with an enthusiastic science teacher around 30 years old with 5 years science teaching experience who is teaching highly motivated and enthusiastic students.
- S**chool 2** is a public school with an excellent reputation in academic, sport, and art. The school has very good science teaching and learning resources. The researcher worked with a well-organised teacher around 40 years old who has been teaching for 21 years. Most of her students are not highly motivated to learn science.
- **School 3** is a religious private school with a good reputation and a multicultural environment. Compared to other schools, this school has less science teaching resources. The students come from a variety cultural backgrounds. The researcher worked with a highly motivated teacher, around 40 years old, who has been teaching for 23 years. Most of her students are not highly engaged in the science classroom.

Results

The results' discussion of the implications of co-teaching and co-generative dialogue is divided into three parts which are the QTI results for teachers' reflections, the results on transforming teacher-students' interactions and the other implications on teaching practices and students' learning.

Questionnaire on Teacher Interaction (QTI) for Teachers' Reflections

This research used the validated questionnaires namely Questionnaire on Teacher Interaction (QTI) was administered to students to provide the teachers' understanding of students perceptions on their teaching. A summary of these eight scales in QTI is presented in a figure that describes how a teacher interacts with his/her students. The figure 1 uses two dimensions to map teacher behaviour: Dominance-Submission and Cooperation-Opposition which is divided into eight sectors. The researchers provide the QTI results on teachers' profile to the teachers. Then, the teachers and the researchers worked together to reflect their interpersonal behaviour in order to transformation their interaction with the students through co-teaching and co-generative dialogue. There were several positive changes felt by the students in teacher interpersonal behaviours as measured by the scales of the QTI, as one of the teachers and the student marked bellow.

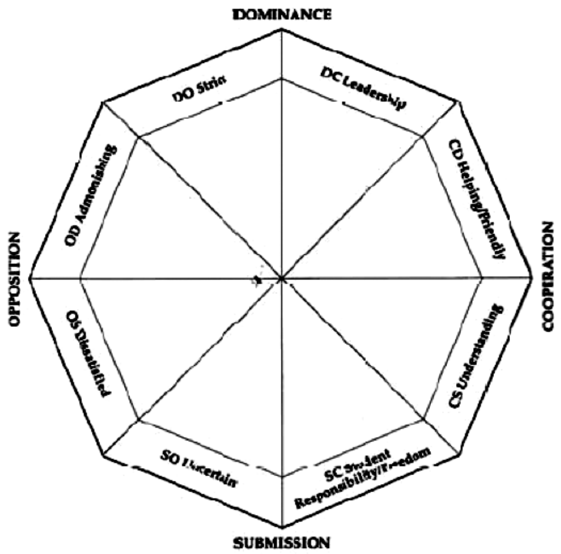

Figure 1. The QTI for teacher profile

"I discovered that my attitude to teaching has changed...to improvise and change my teaching style to accommodate the needs of my students" (Teacher interview)

"... there is an improvement in her behaviour towards the class, as she is more cooperative with us ... She is very caring and works hard to make sure we have understood the lessons" (Student interview)

Transforming Teacher-students' Interactions

It is common in science classroom that teachers' roles and views are shaped by the hegemony of modernism. According to Polkinghorne (1992), the modernism tends to produce the knowledge and control human behaviour. Therefore, the modernist view influences teacher to be the controller, the dominated-power, and the trainer (Taylor, 1998; Taylor & Williams, 1992). Co-teaching and co-generative dialogue provide opportunity to involve self-critical reflexivity for the science teachers as the way to transform their interactions with the students. Even though, it is difficult for the teachers who are used to be a controller in the classroom, especially learn to provide opportunities for students to express their critical voices, through the research, there were transformations in teacher-students interactions. Table 1 presents the QTI scores from pre and post participation in the research on students' perceptions of their teachers' interpersonal behaviours.

Scale	*Test*	*Mean*		*S D*		*Effect Size*	
		Pre	*Post*	*Pre*	*Post*		
Leadership	School 1	4.02	3.06	0.76	0.99	3.41**	0.48
	School 2	4.55	4.57	0.28	0.28	1.36	0.03
	School 3	4.02	3.97	0.49	1.14	0.16	0.03
Understanding	School 1	3.54	3.03	0.94	1.24	1.56	0.23
	School 2	4.21	4.17	0.71	0.72	1.44	0.03
	School 3	3.24	3.63	0.87	1.07	1.63	0.19
Uncertain	School 1	2.29	2.25	0.84	0.75	0.13	0.03
	School 2	1.54	1.54	0.40	0.41	0.27	0.01
	School 3	1.51	1.97	0.53	0.91	1.66	0.30
Admonishing	School 1	2.80	2.80	0.78	0.73	0.00	0.00
	School 2	1.90	1.92	0.71	0.71	1.36	0.53
	School 3	3.06	3.11	0.75	1.17	0.19	0.03
Helping Friendly	School 1	3.97	2.47	0.80	0.92	5.80***	0.66
	School 2	4.52	4.47	0.51	0.51	1.25	0.05
	School 3	2.84	3.43	0.98	0.92	1.90	0.30
Student Responsibility	School 1	2.80	2.34	0.64	0.58	2.31	0.35
	School 2	2.63	2.65	0.54	0.60	0.44	0.02
	School 3	2.25	2.32	0.45	0.81	0.32	0.06

Dissatisfied	School 1	2.44	2.87	0.84	0.93	1.29	0.23
	School 2	1.57	1.62	0.56	0.57	1.43	0.04
	School 3	2.90	2.73	0.93	1.19	0.56	0.08
Strict	School 1	3.16	2.79	0.52	0.60	1.82	0.31
	School 2	2.79	2.79	0.55	0.55	1.00	0.01
	School 3	3.53	3.78	0.58	0.76	1.02	0.18

**$p<0.01$, *** $p<0.001$

Number of Students: School A= 17, School B=32, School C=12

Table 1. Pre and Post Intervention Differences in student perceptions on the scales of QTI

The students participating in this study completed the QTI questionnaire at the start and end of the academic year. The results are varied for all the three schools. School 1, there are two statistically significant differences on the scales of QTI, namely Leadership and Helping Friendly, which was also reflected by the interview results. Then for the school 2, the teacher was already using exemplary teaching practices, with academically gifted students and had excellent interpersonal behaviour. With the result, not much impact was made in the existing teacher interpersonal behaviours. Although, there are no statistically significant differences in teacher interpersonal behaviours in school 3, there are improvements, especially on the understanding and helping friendly scales which are showed by the higher mean and also supported by interview and students' reflective journal. As the nature of case study, the researcher also incorporated the date from the observations, the interview, and students' reflective journals to understand the participants. Based on these methods, the researcher found the transformation in teacher-student interactions as some students commented:

"I think that since you have come to our classroom, our interactions with the teacher have improved a lot. We also ask questions if we don't understand something" (Student interview, September 23, 2010)

"Yes I think the interaction with my teacher has improved, I tend to ask more questions to understand furthermore…"(Student interview, September 25, 2010)

There are also other implications of co-teaching and co-generative dialogue in this research:

Teacher Beliefs

The collaboration during teaching practices provided opportunity for the teachers to examine their beliefs about teaching and learning practices. They learnt from each other to overcome power of technical interest which always played powerful role in their teaching. They tried to put more consideration on practical and emancipatory interests which appreciated the students' engagement during the lessons and possibly students' roles in the future lives.

"I have come to appreciate the value of co-teaching and co-generative dialogue in helping me grow and develop as a teacher"(Teacher interview, November 7, 2010)

"I believe the students should always do their best and never give up, or if they feel they don't understand something – they are empowered to find out" (Teacher interview, December 15, 2010)

Teacher Pedagogy Skills

The co-teaching and co-generative dialogue encouraged the teachers to develop varied teaching methods to engage the students and varied ways to assess students' learning. For example, the teacher and co-teacher developed the practical assessments that were used to assess students' performance in the laboratory. The teachers can see that the students learnt in different ways, some students performed better in practical classes rather than in theoretical assessment which helped them to improve science cognitive achievement.

"I discovered that my attitude to teaching has changed...to improvise and change my teaching style to accommodate the needs of my students" (Teacher interview)

"...our classroom becomes more fun yet educational. The teacher provides different types of learning (videos, experiments, discussions, etc)"(Student reflective journal)

Co-teaching benefits me greatly in being able to optimise each other's strengths (Emilia, teacher interview)

The transforming teaching practices has also influenced the students' learning which are:

a) Students' achievement

The students' achievements are improved, because the teachers worked hard to evaluate and transform their teaching practices as students remarked

"I think all of the students are more engaged into science, especially when compared with last year"(Student reflective journal)

"We learn more; seek more knowledge"(Student interview)

"I have passed my test which makes me very proud"(Student reflective journal)

b) Student Behaviour

The researcher worked with the students who were misbehaving. The students found that co-teaching and co-generative help them to improve their behaviour.

"I think that even though some students misbehave a lot in the class, they are starting to behave a little better than they did before" (Student reflective journal)

"When you and Mrs. Emilia started teaching together I have to say their behaviour has rapidly changed"(Student interview)

Finally, in this research, co-teaching and co-generative dialogue provided the opportunity for the science teachers to transform teacher interpersonal behaviour and teacher-students interaction. It also helped them to transform their teaching and learning beliefs and, pedagogical practices which had implications on students' achievement and behaviour.

Contribution to Science Teaching and Learning

The findings of the research on the co-teaching/co-generative dialogue in science classrooms encouraged science teachers to implement desirable changes in their teaching. The proposed research involved benefits to the community through the application of research results to schools and education systems, by increasing our understanding of effective teaching of science in lower secondary schooling. The implementation of a professional development project is the next stage that could flow on from this research. The areas of need have been identified and teaching strategies addressed and now these strategies can be disseminated to the wider science community.

In addition, the study contributed to researchers and educators who are interested in transforming teaching practices and students' learning, especially in context of using co-teaching and co-generative dialogue. This study also identified students' perceptions of teachers' interpersonal behaviour as an important element in classroom practice.

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Elementary Teachers' Beliefs and Practices for Teaching of Mathematics

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We report beliefs and practices concerning the teaching and learning of mathematics of 13 elementary teachers from a government school system in India through selected items in a questionnaire, interviews, records of discussion during a workshop and classroom observations. Responses to selected questionnaire items indicated that teachers' beliefs varied. The interview and classroom data indicated that in practice most teachers gave primacy to obtaining correct solutions through taught procedures consistent with a "transmission" view. Teachers felt that showing procedures or solution to problems and repeated practice lead to learning mathematics. Teachers believed that students cannot discover procedures on their own and that students have to be taught so as to avoid errors. The possibility of change of beliefs and practice may be strongly constrained by teachers' own mathematical understanding.

Introduction

The position paper on teaching of mathematics of the National Curriculum Framework recognises that teaching of mathematics has been textbook centered with the focus on learning mechanical procedures rather than developing students' power of mathematisation and reasoning (NCERT, 2006). The document recognises inadequate teacher preparation as one of the reasons for the prevalent approach to mathematics teaching. Studies elsewhere in the world have indicated that focus on change in teaching strategies without taking *teacher thinking* into consideration leads to teachers making superficial changes without having any significant change in student learning opportunities (Cohen, 1990). It is therefore important to first understand beliefs and practices that are prevalent among teachers in order to support reform in teaching that is not superficial.

Relation between beliefs and practices

Knowledge, beliefs and emotions have been found to play an important role in shaping teachers' thinking. Although beliefs have been considered as a messy construct (Pajares 1992) there is general agreement in the mathematics education community that mathematical beliefs are "personal philosophies and conception about the nature of mathematics and its teaching and learning" (Thompson 1992). Beliefs play an important role in the way the teacher makes decisions during classroom instruction and thus impact the understanding that students develop as a result of instruction (Wilson & Cooney, 2002). Change or development of beliefs is recognised as a difficult and long term process (Clarke, 1994; Swan, 2006). Research also suggests that belief and practice are in dialectical relationship with each other and influence each other (Guskey, 2000).

Several research studies report dissonances between teachers' beliefs about mathematics, its teaching and learning and actual classroom practices. Various explanations have been offered for such inconsistency between "articulated beliefs" and "enacted beliefs" (Ball & Even, 2009): that some beliefs are held more centrally than others (Pajares 1992), or that the constraints and supports available in the teachers' context allow teachers to enact some beliefs in consonance with their present purpose while assigning lower priority to others. We agree with Aguirre and Speer (2000) that beliefs occur in form of belief bundles that "connect particular beliefs from various aspects of entire belief system" (p.333). How certain beliefs are activated during teaching might depend on long and short term goals (Schoenfeld 2003), the context of the teaching situation, unexpected occurrences during teaching and the knowledge held by teacher to deal with the situations arising during teaching.

Some have questioned the methodologies adopted for belief attribution suggesting that researchers and teachers may have different interpretations and meanings (Speer, 2005). This points to the inherent difficulty of describing teachers' beliefs despite their centrality in influencing teachers' thinking and practice, and the need to draw on multiple sources and use mixed methodologies while ascertaining the beliefs of specific teacher groups.

In this paper we attempt to illustrate some beliefs and practices, related to mathematics and its teaching, of teachers in a government school system using data from items in a questionnaire, interviews and workshop discussions, and classroom observations. The research question addressed by the study is to identify the nature of knowledge and beliefs relevant to mathematics teaching of the teachers participating in the study. The beliefs and practices discussed have to do with emphasizing procedures, the use of repeated practice and preventing the occurrence of student errors as important goals. The four themes together constitute a belief bundle making up a view of mathematics as a subject aimed at obtaining correct solutions using known procedures. We illustrate how this belief bundle is supported by the knowledge of mathematics held by the teachers. We also share insights for the development of tools for assessing teachers' beliefs and practices.

The Study

The findings reported here are part of a larger study from 2009-2011 on collaborating with teachers to develop classroom practices aimed at teaching mathematics for understanding. The study had different phases: professional development workshops and collaborative follow-up of classroom teaching by the first author. Participants in the study were mathematics teachers teaching primary and middle grades in a nation-wide Government school system and were nominated by their principals to participate in the study. Of the 13 teachers from the system who participated in the first workshop, 4 primary and 4 middle school teachers were local, (from the same city) and participated in the two subsequent phases of the program. All the teachers who participated had more than 15 years experience of teaching and were between the age range of 39 to 50 years. Out of 8 middle school teachers only 3 were males and there was no male primary teacher.[1]

Data Collection

Data about teachers' beliefs and practices were collected through Likert type written questionnaires (balanced scale having both positive and negative statements), detailed individual interviews during the professional development workshop, written logs of classroom observation and notes of discussion during the collaborative phase. All the sessions of the workshop were video recorded. All the interviews, and most of the classroom lessons and discussions were audio-recorded. The questionnaire had six parts focusing on teachers' beliefs about mathematics, its teaching and learning, frequency of practices adopted, beliefs about self, beliefs about students, and teachers' personal data. Content validity of both questionnaire and interview was done by experts (researchers, teacher educators) and changes were incorporated as per suggestions.

Participants in the workshop including the 13 teachers from the government school system completed the questionnaire in about an hour. Each interview took approximately one hour. The interview was semi-structured in nature where prompts were provided by the researcher based on the items given in the questionnaire as well as questions about teachers' experiences with mathematics in the past as a student and as a teacher. During the collaborative phase of the study extensive classroom observations were done for 1 primary teacher and 3 middle school teachers from among the group of 13 teachers for a minimum of 20 lessons of 35 minutes each. At least one lesson was observed of the remaining 4 local teachers from the group. The researcher also recorded personal reflections about conversations with teachers, principals and headmistresses along with the circulars, inspection forms and exam papers.

Data Analysis

The Likert scale items in the questionnaire were coded and entered into a spreadsheet for further analysis. Interviews of 4 middle teachers (Teachers A, B, C and D) and 4 primary school teachers (Teachers G, H, I and J) were fully transcribed. Selected interview excerpts have been translated from Hindi into English in this paper.

Themes in this paper were arrived at by data triangulation considering questionnaire responses, interview data, notes of discussions with teachers during the collaborative phase and video recordings of the workshop sessions. Correlation matrices were made for each part of the questionnaire. Then we reviewed the interview transcripts to identify responses related to teachers' views about mathematics and what they considered important in mathematics teaching and learning. The themes that emerged as important from the teachers' responses related to the following:

1. Primacy of obtaining correct solutions to problems through learnt procedures
2. Importance of repeated practice
3. Importance of teaching by showing procedures or solved examples
4. Dealing with student errors

1 The number of male teachers at the primary level is much smaller than female teachers in this school system.

We used these themes to revisit teachers' responses to items in the questionnaire. Nine statements of belief taken from two parts of the questionnaire focusing on teachers' beliefs about mathematics, and its teaching and learning were identified as important for the themes listed above. Table 1 shows the distribution of responses of the 13 teachers to these statements from “strongly agree” to “strongly disagree”. Table 2 shows the correlation between the responses to the statements.

No.	Statement	Strongly agree	agree	Unsure	disagree	Strongly disagree
1	Students should be allowed to make mistakes and then discuss them.	3	9	0	1	0
2	Being good at mathematics means being able to perform calculation quickly and accurately.	1	4	2	4	2
3	If a student practices solving all the problems in the textbook two or three times, that is the best way to learn mathematics.	1	2	2	6	2
4	The key to learning mathematics well is to repeat the textbook exercises two or three times (or more).	0	4	0	6	3
5	The best way to teach mathematics is to explain one procedure at a time on the blackboard and then to make students practice it.	1	6	1	4	1
6	When students make errors, the best remedy is to make them repeatedly practice these types of problems.	4	4	2	1	2
7	Students cannot discover procedures (methods) for calculation on their own. They need to be taught these procedures. (There may be rare exceptions.)	1	7	0	3	2
8	A teacher should teach each topic from the beginning assuming that the students know nothing.	4	6	0	1	2
9	A teacher should explain things carefully in the beginning so that students can avoid mistakes.	3	8	0	2	0

Table 1. Frequency distribution of teachers' responses to selected items in questionnaire

	1	2	3	4	5	6	7	8	9
1	1.00	-0.76*	-0.23	-0.31	-0.56*	-0.57*	-0.58*	-0.59*	-0.68*
2	0.76*	1.00	0.49	0.21	0.66*	0.63*	0.55*	0.56*	0.74*
3	0.23	0.49	1	0.66*	0.74*	0.59*	0.72*	0.54*	0.62*
4	0.31*	0.21	0.66*	1.00	0.76*	0.50	0.74	0.56*	0.61*
5	0.56*	0.66*	0.74*	0.76*	1.00	0.80*	0.70*	0.70*	0.73*
6	0.57*	0.63*	0.59*	0.50	0.80*	1.00	0.51	0.37	0.51
7	0.58*	0.55*	0.72*	0.74*	0.70*	0.51	1.00	0.63*	0.72*
8	0.59*	0.56*	0.54*	0.56*	0.70*	0.37	0.63*	1.00	0.83*
9	0.68*	0.74*	0.62*	0.61*	0.73*	0.51	0.72*	0.83*	1.00

Table 2. Correlation matrix of 9 items (* values are significant at .05 level)

(Values from 1 to 5 with “Strongly agree” =1 and “Strongly disagree” =5)

Teacher Code	A	B	C	D	G	H	I	J
Teachers' mean on scale	2.7	4.4	2.2	2.3	3.9	2.9	2.9	2

Table 3. Teachers' mean scores on the scale (after reverse coding for Item No. 1 in Table 1)

Results

Table 1 shows that for most statements, there were differences among the teachers, with some agreeing and some disagreeing, indicating that the items are able to discriminate among teachers who have different articulated beliefs about teaching mathematics related to the themes listed above. The inter correlation (calculated taking values from 1 to 5 with "strongly agree"=1 and "strongly disagree"=5) among the items are significant for most of the items at .05 confidence level interval (above 0.51) and some for .01 (above 0.64) and .001 (above 0.76) levels. This suggests that the items potentially form a scale. The cronbach alpha of these 9 items is 0.91 (after reverse coding for the negatively correlated item no. 1) indicating good internal consistency. The means of teachers on the putative scale indicate the variability among the teachers responding to the questionnaire with the highest mean of Teacher B with mean 4.4 and lowest mean of Teacher J of 2.

In the interviews, teachers often expressed views that tended to agree with statements 1 to 9 in Table 1, that is, tended more towards the lower end of the scale than the distribution of responses in Table 1 suggests. The responses of Teacher G, in contrast, were generally consistent with her position closer to the upper end of the scale. We will discuss below some excerpts from the interviews along with the questionnaire responses under the four themes identified previously.

Primacy of obtaining correct solutions to problems through learnt procedures

Teachers responses in Table 1 show variation in agreement for viewing learning of mathematics as learning to obtain correct solutions while interview responses and classroom observations indicated that most teachers gave primacy to correct solutions. In the interview teachers were asked to describe a typical mathematics lesson that they taught. Most teachers described how they try to elicit the correct solution from students by explaining the question, sometimes focusing on textual cues and showing or recalling solutions to similar problems. The primary teachers focused on identifying the correct operation to be performed with numbers while middle school teachers focused on methods and specific types of questions and their solutions.

> First I explain one or two times then answer comes out orally, If not I solve the question... I explain on the blackboard and then give some connected problem. Sometimes I solve on the blackboard and then give them. (Teacher G)

Table 1 shows that 8 teachers agreed or strongly agreed that students cannot come up with solutions on their own, while 5 teachers disagreed or strongly disagreed with this view. Teachers G, H and B, who were among the latter, said in the interview that students could come up with the procedures of their own. But deeper probing revealed that they felt that students can come to know different procedures from elsewhere (magazines, parents) and only a few intelligent students can discover procedures and thus they have to be taught.

> Children bring their original ideas... their world is very big... he learns from lot of things other than teacher in the school e.g. Internet, father in specific profession.... Very few children able to give justification and explanation on their own. (Teacher G)

> Justification and explanation they can arrive [at] if the child is bright. (Teacher B)

The new textbooks in primary classes have less emphasis on standard algorithms for calculation than earlier textbooks, and greater emphasis on understanding problems situated in contexts and encouraging students to find their own ways of solving them. The discussion of problems in the classroom however still involved focus on the procedures and getting right answers to the problem. In most of the lessons observed the discussion of a problem typically ended with determining the correct answer and the student or teacher writing the correct solution or method on the blackboard and few opportunities for students to voice their understanding or develop strategies of their own. Students too expect discussion on right answers and method and even when a teacher tries to initiate a discussion of why the procedure works, students find it difficult to engage with it. In Teacher G's class most of the students went to private tuitions and often many already knew the correct answers when the teacher discussed a problem from the textbook. The teacher then called students to the blackboard to solve the problem and evaluate the method. When she tried to focus students' attention on understanding the concept, students did not engage readily as they already knew the procedures to get the correct answers. During the collaboration phase, her focus on asking why questions and developing justifications through visual representations however did succeed in engaging some students and in developing reasons for their answers.

Importance of repeated practice

The focus on procedures in teaching is consistent with giving students many similar problems for repeated practice assuming that it will help students in memorising the procedure as well as knowing which procedure is to be adapted for solving a certain kind of problem. Responses to questionnaire items related to this theme (Statements 3, 4, 5 and 6) show a variation, indicating that some teachers considered practice to be important while others did not. During the interview however, teachers affirmed the importance of practice. Some teachers felt that the textbook did not contain enough practice questions and so they themselves made practice questions for students. This was more common among the middle school teachers while primary teachers mostly asked students to repeat the work done in class as homework. However, Teacher A diverged from others as she felt that repeated practice of very similar problems amounts to rote memorisation.

> I don't repeat problems done in class. This practice is there in coaching classes which emphasizes rote learning. (Teacher G)

> Practice is required to keep what is learnt in memory so that they don't forget by the next chapter.(Teacher B, who had agreed with statements 4 and 5, but disagreed with statement 3)

> Homework is similar problems to those done in class. I give 50 problems in 2 days...Because in one day when they solve [many] problems then only they get it. (Teacher A, who had disagreed or strongly disagreed with statements 3, 4 and 5)

> They should become thorough means that they have to do lot of questions even when they know the principle. Along with that whatever is there in the textbook... I give similar questions for homework by changing the angles, distance, speed to make them thorough. I make students repeat the questions if they are important like linear equations, age problem, upstream downstream questions, because I want to make them familiar with the sentence language. I am doing on the blackboard and they are copying so whether they understood or not, I can know only when they do it again. (Teacher C, who had agreed or strongly agreed with statements 3, 5 and 6)

Importance of teaching by showing procedures or solved examples

In the questionnaire, the teachers responded to the following two statements.

1. The best way to teach mathematics is to clearly show the procedures (methods) to solve the mathematics problems.
2. The best way to teach mathematics is to show students how to solve some example problems.

There was considerable variation in the responses to these items and the correlation between them was zero. We believe that some teachers may have interpreted these items as mutually exclusive. The purpose of these items was to probe teachers' views on *showing* procedures or solved examples. So we combined responses to these items by taking the minimum of the response codes to the two items, which showed whether teachers agreed with at least one of the statements. The combined responses to the two items indicated that 9 teachers agreed or strongly agreed with at least one of the statements. 4 teachers disagreed or strongly disagreed with both the statements. The combined response of two statements was significantly correlated (at .05 confidence level or more) with all statements in table 1 except statement 4.

In the interview while talking about a typical lesson teachers described how showing solutions and steps of procedure is a major routine in their classroom teaching. Teacher G and A had consistently disagreed with the two statements, yet their explanations were focused on procedures.

> Explanation is the explanation of steps of procedure... (Teacher A)

> I tell them the topic, I generally do 2 questions in the class. One I explain properly...second one is done by students... (Teacher D agreed to 1, unsure about 2)

> After giving explanation for 2-3 examples, page number, activity is there then you can solve the questions. (Teacher H disagreed to 1 and agreed to 2)

Teacher H also elaborated about the lesson that she liked in the new textbook where lots of questions for different operations were there. She said that she made lots of similar questions for students. She felt “that is maths, multiplication and addition is coming [i.e., present]”.

Teacher B who had agreed to first statement and disagreed with the second one, elaborated how participation in the workshop and observing teaching focused on concepts has lead to her to re-evaluate the way she taught mathematics.

> After attending this course I feel it is possible. We used to teach everything in textbook. I saw yesterday the observation of classes. After that I felt that teacher can just give the concept and need not solve each and every question. Not giving the question but giving the concepts. If this method is adopted – give the concept and steps and all are secondary... (Teacher B)

Avoiding student errors

Although teachers reported change in their teaching approaches after the introduction of new textbooks, there was indication that not much had changed in terms of learning opportunities for students. One of the objective of the new textbooks was to allow children to "generate new knowledge" through imaginative activities and questions (NCERT, 2006, Foreword). However teachers' views were not conducive to meeting this objective. As we saw earlier, teachers did not really think that students could come up with solutions on their own. Moreover, their responses reflected a concern with channelling students' thinking in ways that would prevent them from making errors. 11 teachers either agreed or strongly agreed that teachers should explain things carefully in the beginning so that students can avoid mistakes while most teachers (9) also agreed that students be allowed to make mistakes and discuss them . This can be explained by teachers having acquiescence bias. Alternatively, it could be that teachers do not consider these two items as mutually exclusive in the sense that they teach in manner where they try to tell students clearly how to solve something but are aware that mistakes do happen and discuss mistakes. Classroom data corroborated that errors were avoided and when they occurred, students were told to how to do the problem correctly.

The interview responses and classroom observations also indicated that teachers rarely made efforts to understand why the student had made the mistake. The strategies that teachers adopted for addressing student errors was to indicate where the correction has to be done and asking students to do repeated practice (Table 1, statement 6). In the interview teachers said that they also ask 'good' students to explain to other students. However many felt that errors had to be rectified immediately .

> Wrong answer get corrected on the board only (Teacher J)
>
> If somebody gets wrong answer I ask him/her to do again or I tell that you have done steps till here correctly (Teacher G)
>
> If somebody got a wrong answer I help by first looking at their knowledge. If it is a knowledge problem I tell them what to do e.g. Formula..If they make calculational mistake I tell them. (Teacher D)
>
> Which step they have gone wrong I will tell. (Teacher C)

In one of the workshop sessions, teachers discussed student errors and the possible causes of such errors. After a long discussion on various hypotheses about what the underlying thinking of students that may have led to the errors, one of the teachers remarked, "In fact we know their [students'] mistakes but we don't really see into their thinking".

Discussion: Relation between beliefs and Knowledge

The findings discussed above suggest that teachers' beliefs that shape their practice may be closer to a transmission view of mathematics, that emphasises obtaining correct solutions, explicit teaching of solutions by showing, repeated practice, and avoiding or dealing with errors by emphasizing correct solutions. Teacher exposure to ideas of curriculum and textbooks could be the reason why some teachers agreed with constructivist view in the questionnaire but are unable to enact them in practice as suggested by interviews and classroom observations. This explains the inconsistent responses e.g. Item 1 and 9 in the questionnaire. Because of the social position of teachers as "curriculum implementers" it would be difficult for them to acknowledge views different from the ones prescribed by national curriculum. This further increases the complexity for ascertaining beliefs as professed beliefs might not be "true" beliefs held by teachers while teachers' practice might be a better reflection of the beliefs held by teachers. It also reflects that just by exposure to a different curriculum or textbooks it may not be possible to change teachers' "enacted beliefs".

The teachers' interview responses suggested one possible reason why these beliefs may be difficult to change, despite teachers' exposure to and awareness of the new ideas embodied in curriculum and textbook revision. In the questionnaire, teachers responded to the statement "It is important for students to not only know procedures (methods) for calculation but also why the procedures work." All 13 teachers either agreed or strongly agreed with this statement. However, the interview responses and interaction during the workshop showed that teachers themselves were unclear about why mathematical procedures work.

In the interview when primary teachers were asked how would they explain a division of say 36036 by 9, 3 out of 4 primary teachers explained the procedure. Only Teacher A said that she will focus on place value while explaining the procedure and might use the analogy of sharing in groups if a student has not understood. She asserted that "concept and procedure both should be emphasised". Teachers often resisted engaging with conceptual explanation as they felt that students might get confused.

> Just like you have names these digits have names as ones, tens, etc....In addition we start from ones but for division we start from left to right...3 is less than 9 so you can't divide because 3 doesn't come in 9's table. So then you should take 2 numbers... small classes if you say about tens place, hundreds place, children will get confused... but you can say for addition and number names. We have to see that child is not confused and the child gets confident. (Teacher J)

Thus relationship between beliefs and practice might be more complex with knowledge about mathematics, its teaching and learning playing as an intervening variable in bringing about belief change. This calls for studies where teachers' development of knowledge is seen in relationship with the change in "enacted beliefs" that are held by teacher and exploring the process through which such knowledge can be developed.

The study also raises questions on the use of questionnaires to assess beliefs of teachers. The questionnaires afford assessment of large number of teachers but fail to capture the complexity of beliefs as to how different beliefs are connected with each other and the factors that might be influencing activation of some beliefs and thus influencing teaching. Agreeing to an item in a questionnaire does not rule out existence of other conditional factors or other connected beliefs that exist. For e.g., teachers agreed that students can come up with their own procedures but probing revealed that they were thinking only of a classroom situation where students might share procedure learnt from magazines, parents. For other items also where teachers agreed for more constructivist view in questionnaire, the data from interview and classroom observation was inconsistent with articulated beliefs.

The findings described here as well as findings from studies conducted elsewhere suggest that teachers' enacted beliefs are more resistant to change than their explicit assent to reform oriented views. Further, the findings suggest interaction between beliefs and knowledge, that inadequate mathematical knowledge may be a hurdle to change of belief. This may have implications for teacher development programs, where there is a need not only to create spaces for reflection on and revisiting of beliefs, but also for strengthening teachers' mathematical knowledge.

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Advantages and Limitations of a Mixed Method, Technology Based Approach to Evaluating a National, University Level STEM Education Program

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This paper discusses the strengths and limitations of a technology based mixed method evaluation of a US national education program for plant breeders. The education program also uses technology to deliver instruction and create community. Mixed methods included participant observation, surveys, case studies, focus groups, social network analysis and interviews. The results of the evaluation of the program are presented and the implications surrounding the use of mixed methods and technology to evaluate such programs are discussed.

Introduction

Mixed method research and evaluation are tools commonly used by STEM researchers and evaluators to investigate program or policy merit and worth (Creswell, Trout, & Barbuto, 2002; Teddlie & Tashakkori, 2008). In many situations, a combination of different types of information provides multiple stakeholders with information they can use with confidence (Chelimsky, 2007). Greene (2007) described that mixed method studies may be generative, as paradox and contradiction are engaged and "fresh insights, new perspectives, and original understandings" emerge (2007, p. 103). Other mixed method authors share this belief in the promise of mixed methods. For example, Tashakkori and Teddlie (2003) used the term *gestalt* to indicate how inferences from mixed methods may be greater than the single method components. Barbour (1999) described mixed methods as a whole greater than the sum of its parts. By using multiple, diverse methods, researchers may corroborate findings to increase confidence in the inferences drawn from them.

The advent of the internet has allowed communication among formerly isolated or widely dispersed individuals. In the case of STEM, this enhances the educational and research capacity by connecting students and researchers at distant locations. STEM education programs that take advantage of these new opportunities are different from traditional programs and hence require rethinking of traditional approaches to STEM program evaluation. These new programs need to be evaluated using technology based mixed methods approaches (Green, 2007; Cresswell & Plano Clark, 2010). This paper discusses the implementation of such an evaluation and its advantages and limitations to provide guidelines for future evaluations.

The project evaluated, the Triticeae Coordinated Agricultural Project (TCAP), is a complex, University-level educational program being implemented at different institutions across the United States. The TCAP is funded by the United States Department of Agriculture. It is an effort to improve the quality of wheat and barley breeding and increase the numbers, diversity and skills of plant breeders. The educational component of TCAP includes researchers and faculty from over 20 universities across the United States. This component consists of providing education and research opportunities for graduate students in plant breeding programs and partnering with faculty from eight minority serving institutions (MSIs) to develop interest in plant breeding careers among MSI undergraduate students. The project is relying heavily on developing a networked learning community. This complex project has five major clusters of activities including: relationship building with MSIs, fostering of social networking between and among all groups involved in the project, online course development and presentation, incorporation of inquiry based learning into courses, and development and use of motivational videos/curriculum in courses at a variety of levels. The belief is that these activities will produce more, better prepared and connected plant breeders who come from diverse communities, as well as improved content and teaching procedures in plant breeding courses.

The objective of the evaluation was to document baseline perceptions of the participants. This would provide information upon which to base future programming as well as an initial data point from which to measure future change as the TCAP continues. The objective of this presentation is to document the advantages and limitations of a technology based mixed method approach to evaluation of a complex, University-level STEM education initiative.

Initiation of the evaluation

The first step in the process of designing the technology based, mixed methods evaluation was to develop a logic model for the educational program. Logic modeling is a fundamental process to help program staff to map out their program's theory of action and inform evaluation activities and priorities. Modeling is usually conducted face-to-face in a group process over a period of several days (see Mayeske & Lambur, 2001; Taylor-Powell & Henert, 2008; W.K. Kellogg Foundation, 2004). However a face-to-face process was impossible in this setting and telephone and web based conferencing was used. The evaluation team played a neutral role helping members of the TCAP educational committee come to agreement on what activities and goals were important. The process included four meetings over a period of one month, with each meeting lasting approximately two hours. Adobe Connect, a web conferencing tool, allowed for everyone to see a shared screen where documents were presented and edited simultaneously. Telephone conferencing also supplemented the calls when there were audio issues with Adobe Connect. Discussion took place primarily through the audio and written chat features. The logic model that was developed is presented on the following page.

Based on the logic model the mixed methods evaluation was designed to assess outcomes through monitoring, a focus group, social networking, surveys, interviews, participant observation, and case studies. A combination of web and phone conferencing was used, as well as in-person activities to foster relationships. The evaluation also made use of the available audio recordings of the communications that took place among participants via the web community hub. This allowed the evaluation to examine the type and depth of communication in terms of how passive or active the members were in connecting with each other. The evaluation will continue for the five years of the project. What is reported on here are the results from the first year.

Methods used in the evaluation

Monitoring data were collected by the project personnel and included demographic information as well as school background and participation in project activities. A 90-minute focus group with nine MSI faculty members who were not part of TCAP was held early in the project to obtain their perceptions of the proposed TCAP small grant program where funds from TCAP would be awarded to MSI institutions to support students and research at the MSI. The discussion explored the potential for MSI participation and how best to structure that participation.

Three online surveys were conducted, one of the principal investigators (PIs) in the project with 42 of the 54 PIs responding (78%), one of the graduate students with all 12 of the students responding and one of the principal investigators from the MSIs with all eight responding. All surveys were designed collaboratively with project staff members and think alouds were conducted to verify understanding. The graduate student survey assessed perceptions of plant breeding education, interest and motivation in the plant breeding field, perceptions of the TCAP educational programming, and collaborative networks with other students, faculty, and researchers within and outside of the TCAP. Similarly the TCAP PI and MSI PI surveys also assessed perceptions of plant breeding education and collaborative networks, but additionally assessed perceptions of TCAP educational components and relationships with PIs from TCAP and MSI institutions.

Telephone interviews were conducted with TCAP students (n = 6) and PIs (n = 7). Students and PIs were selected for the interviews based on their background and university characteristics. Students were asked about their perceptions of the educational component of TCAP, the online learning community, and their relationships with other TCAP students and faculty. PIs were asked about their relationships and collaborations with other TCAP and MSI institutions, their involvement in and perceptions of the educational component of TCAP and their beliefs about recruitment efforts.

The educational components of the TCAP included online course meetings as well as webinar broadcasts. One member of the evaluation team acted as a participant observer of these online activities and also perused all of the related archived materials.

Case studies were conducted at three MSIs, selected based on their diverse sizes, locations, and types of institutions. The site visits lasted one to two days and included observations and interviews with members of the MSIs, as well as participating faculty members and students.

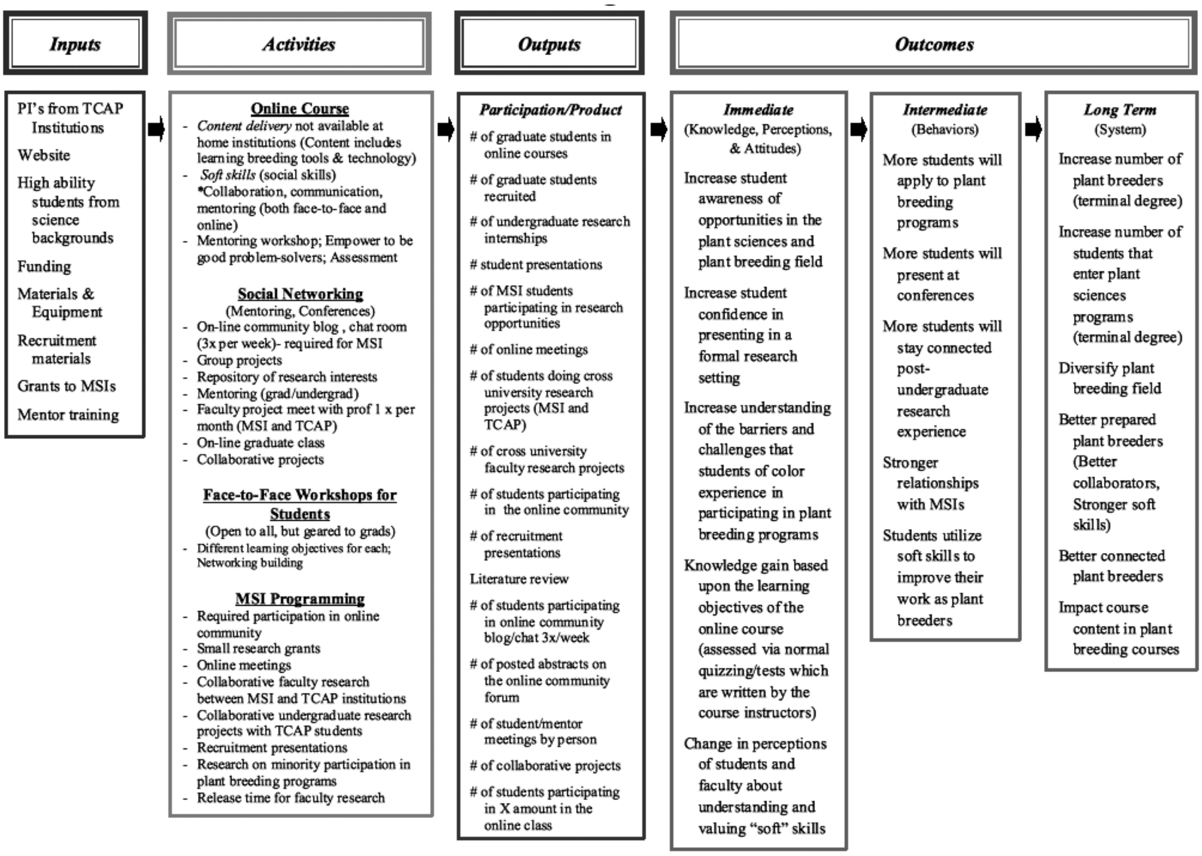

Figure 1. TCAP Logic Model

Results from the evaluation

Overall the MSI faculty participants in the focus group were optimistic and supportive of the potential that participation in the TCAP could provide for them and their students. Participants wanted more details about programmatic elements. The comments about how to structure the participation in the TCAP could be summarized into one overarching theme with several sub themes. The overarching theme was equality. The subthemes included respectful collaboration, mutual understanding, articulation, continuing relationships, and faculty and student support.

Survey data indicated a range of findings. For instance, TCAP graduate students felt "very confident" in working collaboratively (83%) while almost half of the students surveyed (42%) felt "very confident" about genetics when asked to rate plant breeding knowledge areas. With respect to TCAP faculty, the majority of PIs (81%) reported research to be the most important educational component of TCAP. About one-third of the PIs identified lack of interest and/or awareness of plant breeding as the top barrier to increasing the number of underrepresented minorities in plant breeding.

A cross-comparison study of TCAP faculty and graduate students was conducted by comparing survey results of similar sections. Findings indicate that students seem to have less confidence in areas that PIs consider to be very valuable and some areas students report having confidence in are areas was considered by the PIs to be less valuable Both students and PIs agreed about the importance of educational processes in plant breeding.

Students felt the most important aspect of TCAP was the opportunity to network with faculty and students from across the nation. They appreciated having a network of shared resources and expertise. They invariably mentioned how they felt TCAP would help them develop collaborative networking opportunities.

The faculty interviews show that they are excited about the TCAP and the opportunities it presents for working together about important research topics. The PIs interviewed also felt that the TCAP has expanded the types of researchers that are involved in the discussions about TCAP research.

The webinars exposed TCAP graduate students to each other's research as well as content pertinent to the student's research. Additionally, the webinars provided opportunities for students to troubleshoot research projects. While the online course meetings achieved the goal of exposing students to discussions of content with each other and in a whole class discussion, the discussion board itself did not appear to serve its intended goal of spearheading group discussions.

The case studies of the MSI institutions provided strong contextual information. Students at MSI institutions expressed a genuine excitement to be a part of the TCAP. Students hoped for content knowledge and expanded networks and were excited to belong to a TCAP community and to interact with TCAP graduate and undergraduate students. All students interviewed indicate that they are looking at this experience as an opportunity to improve their skills and help them prepare for graduate school. How best to recruit students was an issue brought up by both the students and the faculty members. All also mentioned the potential for development of strong, collaborative relationships between the MSIs and TCAP institutions. While faculty and students appeared enthusiastic about the educational component, they did offer suggestions for improvement.

Advantages and limitations of the evaluation approach

The use of mixed methods in this evaluation had both advantages and limitations. The advantages included a variety of information, different perspectives on the project, and a balance of measurement biases. The limitations included need for a variety of expertise, time for data collection and report development, and synthesis of a large amount of information.

Evaluators turn to mixed method methodology to address the practical challenges and resultant uncertainty of using any single method (O'Cathain, Murphy,& Nicholl, 2007). Both post-positivist and interpretive methods have limitations. For example, Weiss (1995) described the challenges to conducting randomized controlled studies, and the mechanisms to identify causal mechanisms in interpretive research have been considered to require further development (Johnson & Onwuegbuzie, 2004).

The methods used in this evaluation represented a range of methodological approaches which provided a balance of the biases inherent in each individual approach while providing diverse information that produced a comprehensive picture of the project. Surveys, focus groups and interviews share the bias of self-report but interviews allow for more probing and more emergence of the ideas of the interviewees as opposed to the preconceived ideas of the survey developers. Focus groups allow for 'group speak' and the development of group consensus. Participant observation and coding of recorded interaction provides an independent look at the conduct of the project. Case studies allow the development of situated and contextualized understanding of the project operation. On the other hand, implementation of these different techniques required the use of a team of evaluators with a range of expertise in the different methodologies as well as a substantial amount of time and expense to collect and analyze all of the data. It also was difficult to synthesize the different types of data into a coherent picture of the project. How and when to best to mix methods is a subject of debate (Greene, 2007; Creswell & Plano Clark, 2010). Using mixed methods is recommended when convergence of findings is desired for triangulation, when diverse perspectives are desired to expand one's understanding of a project, and/or if multiple stakeholders have differing information needs.

The technological aspects of this evaluation also had advantages and limitations. Advantages included archiving of the online interactions, reduction of time and travel costs, convenience, and potential to involve everyone from everywhere. Limitations included misunderstanding, technological difficulties, and lower rates of interaction and awareness.

The presence of the internet allows quick communication and written documentation of conversations. It also allows for the digital capturing of video presentations or other types of communication that can then be used as data for evaluations. This was a real advantage in the assessment of the communication and social networking components of the project. Because of the networked nature of the community, the evaluation was able to understand the 'real time vibe' of the network. However, how to optimize communication via the network is an ongoing issue. In conducting the evaluation discussion via internet and telephone did not always result in clear communication. Audio issues were a re-occurring problem and because the webcam feature was used only once during the process, it was impossible to gain understanding through body language and facial expressions. Sometimes some of the members met together face-to-face, while others logged in from their own computers and phones. This resulted in differential discussion and feelings of involvement. The use of the internet lessened geographical barriers and provided the opportunity for everyone to participate while saving travel time and cost. The convenience of the meetings also allowed the scheduling of more frequent meetings. To optimize the use of technology in a STEM evaluation, the technology needs to be carefully tested, technological failures need to be anticipated and plans for how to deal with any developed in advance.

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Mathematisation – Vertical and Horizontal

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The idea of mathematisation which was espoused among others by Freudenthal was further developed by reflecting on the design practice by Treffers. He first made the distinction in 1976 between horizontal and vertical mathematisation to indicate the different aspects. By 1993 this differentiation was further clarified to distinguish the different roles that contexts can play in mathematics education. The process of level-raising by organising, symbolising and model building by starting from a paradigmatic situation in which children can orient themselves is termed vertical mathematisation, while the organising of contexts to make them applicable to mathematical treatment using the existing tools is termed horizontal mathematisation. NCERT textbooks are analysed through this lens and it is argued that while there are possibilities for supporting horizontal mathematisation, opportunities for vertical mathematisation are missing.

The National Curriculum Framework 2005 (NCF, 2005), which sought to introduce new mathematical practices into classrooms considered 'mathematisation of the child's thought processes' as the 'one main goal' of mathematics education in schools, arguing, echoing Wheeler, that it is 'more useful to know how to mathematise than to know a lot of mathematics'. (NCERT, 2006, p 1).

Mathematisation is a word that strikes a chord among many, especially those who have been pained by the mechanical manner in which mathematics has been taught and has been used by many to capture what they would consider as the heart of the mathematical enterprise – the thinking and the reasoning. In this paper I present the idea of mathematisation as formulated originally by Freudenthal and later modified and developed through practice by Treffers and others in the RME (Realistic Mathematics Education) tradition.

Freudenthal in his 1973 volume *Mathematics as an Educational Task*, made a case for mathematisation. His appeal for mathematisation was strongly related to his conception of mathematics as a human activity and his view of learning as reinvention. Writing as he was in the period that structuralist 'New Math' (that focused on set theory and the abstract deductive structures of mathematics) was sweeping across the world, Freudenthal's obvious concern was to present an analysis of mathematics – not as a ready-made product but as 'acted out mathematics'. Taking the example of complete induction, he argued against the 'deductive course (which) is to derive from Peano's axioms the principle of complete induction as a theorem and to apply it afterwards on various examples'. This, he called as an example of **antididactic inversion** and that 'the analysis of the learning process shows that the didactic course is precisely the opposite.' (Freudenthal, 1973, p122).

The mathematisation process that Freudenthal advocated was also related to his understanding of mathematics as an activity of organising fields of experience, in which the means of organizing the lower level becomes the subject matter on the higher level. (Freudenthal, 1973, p 123). His passionate appeal to see mathematics as a human activity and not as ready-made, made him argue that 'there is no mathematics without mathematizing, in particular, no axiomatic without axiomatising, and no formalism without formalising.' He added that 'the problem should grow out of the situation, and the child should learn to recognize the problem in the situation. Raising a problem is mathematics too.'(Freudenthal, 1991, p 134-35)

Mathematisation And Didactisation

The understanding of what mathematisation entails developed with the Wiskobas project in which from 1968 onwards curriculum development work started in the Netherlands, involving classroom intervention (Treffers, 1993). Reflecting on a decade of the Wiskobas experience, Treffers in 1978 formulated an understanding of the levels in the process of mathematisation and concomitant process of didactisation (Treffers 1978), which has since become the common basis for understanding within the RME research community (van den Heuvel Panhuizen, 2001,Gravemeijer, 2000).

The idea of level-raising that developed in this period is shown by Treffers by taking example of a set of 11 questions dealing with ordered counting (Treffers, 1978, 43-81). He chose the example given below to detail out a path of mathematisation in the classroom (Treffers, 1978, p 58-66).

> 1) Someone rides every day the route from a via b to c following the shortest way. He decides to take every day a different 'shortest' route abc. How long can he continue to do this?

Treffers presents the landmarks in the process by which two children who had not been exposed to combinatorics solved the above problem.

Step by step children solve this problem, first recognizing what 'route' means and then what 'different' means, discover to their surprise that there can be an 'outside' route that is as short as the inner route. First they colour the different routes and then decide to draw them separately to make it clear. While they are busy sketching separately the different routes the teacher asks them

> 'how many pieces are there from a to b, followed by how many steps are there to the right and how many below?' When the teacher asks them whether they can write the different routes in terms of right and below, a new stage in the trajectory opens up for the children. They go through further schematisation of this representation by making tables of the different routes using the new characterisation and conclude that there are 13 routes. The teacher then makes a tree diagram to take the conversation further to see how many possibilities are there to go further once having reached b and children go on to notice the relationship and 'see' that there are 30 routes. (Treffers, 1978, p 60-64).

Adri Treffers, reflected on such classroom practices to develop an understanding about the different processes of organisation involved in mathematisation. Specifically reflecting on this lesson he showed how the process of organising, involving 'recognising commonalities and differences', 'systematic approach' 'symbolisation' 'generalisation of a particular solution' and so forth (Treffers, 1978, p 58) was not a process that 'came up by itself' and needed to be steered and supported through specific didactical methods. ((Treffers, 1978, p 59)[1]. He identified eight core practices and characterised them through the term didactisation and argued that 'just as mathematisation indicates the core mathematical activities, didactisation points to the core of the didactical practices' (Treffers, 1978, p 65).

Learning principles (mathematisation)	Instructional Principles (didactisation)
Learning as construction	Laying a concrete orientation basis
Level- character of learning	Provision of models, schemes and symbols
Reflecting aspect of learning	Assigning of special tasks with free production and conflict problems
Learning as a social activity	Interactive instruction
Structuring and schematising character	Intertwining of learning strands

Table 1. Learning and Instruction principles (modified from Treffers, 1991, p 26)

Later he went on to identify five learning principles and connected five instruction (didactic) principles, in a process where mathematisation is expected to take place, with each of these aspects being connected to all the others (Treffers, 1991, 24-27).

Horizontal And Vertical Mathematisation

As a part of the process of reflecting on the experiences of classroom interactions Treffers not only laid out the relationships between mathematisation and didactisation, but already by 1976 made the distinction between two different forms of mathematisation - horizontal and vertical (1978, p 78-79).

The earlier cited example, in which the form of representation achieved becomes a tool for dealing with new situations, was seen as a case involving vertical mathematisation. In this various forms of mathematical treatments such as generalisation and symbolisation played important roles. At the same time he also stressed the importance of horizontal mathematisation which involves 'effort to schematise a problem till a problem statement is created that can be solved using mathematical methods' (p79). He pointed out that one of the 11 questions considered had a question which could not be solved merely by using the grid route problem that

1 I have relied on the 1978 thesis and translated it while writing. The English translation of the thesis of Treffers was later published (Treffers, 1987), but I have not had access to it as of now.

children were familiar with. This involved finding out the 'composition of boys and girls in the family', in a survey of 160,000 families that have 4 children (Treffers, 1978, p 57-58). Treffers concluded that the question was posed at too abstract a level and that children should have had enough opportunity to understand chance and probability before such a problem could have been solved using combinatoric methods (p 78). He said, since there did not seem to be any mathematical method available for these children for solving the problem, empirical methods such as tossing a coin had to be first used to make the partitions and only then slowly would they come to see that the problem can be solved using grid routes with which they were already familiar. In such cases he said that the problem had to be first transformed using an empirical approach of observation, experiment and inductive reasoning before the problem can be dealt with using strictly mathematical methods. Therefore he characterised this as a case of horizontal mathematisation.

Later Freudenthal also accepted this distinction as valid (Freudenthal, 1991, 41-44) and his characterization that 'horizontal mathematization leads from the world of life to the world of symbols: In the world of life one lives, acts (and suffers); in the other one symbols are shaped, reshaped, and manipulated, mechanically, comprehendingly, reflectingly: this is vertical mathematization' has become a leitmotif for this distinction (Gravemeijer & Terwel 2000; van den Heuvel-Panhuizen, 2001). Freudenthal mentioned that for a long time he hesitated to accept this distinction: 'horizontal mathematising which makes a problem field accessible to mathematical treatment …versus vertical mathematising which effects the more or less sophisticated mathematical processing." According to him, he declined to do so, because he felt that the equal status in practice of both these activities would be endangered by this distinction. He had experienced that many mathematicians interested in education narrowed mathematising to the vertical component while many educationists turning to mathematics restricted to the horizontal one (Freudenthal, 1991, p 41).

Yet as the experience and reflection further progressed, the formulation of the distinction further evolved and got clarified and we can say that the understanding developed that both forms of mathematization deal with forming a model of reality but in different ways. In *horizontal mathematization*, the process of mathematization focuses mainly on ordering and schematising and building a model of the reality so that it becomes amenable to be dealt by mathematical means. As for example in the case of the discussion a horticultural image of Van Gogh's Sunflowers. Treffers says that such 'integrative themes have a specific horizontal mathematising purpose; they are primarily directed at the application, practice and relating of learned knowledge and skills in context situations." (Treffers, 1993, p 94). Even though these are 'application' contexts, they need to be distinguished from what are normally called 'word problems' that are disguised bare number problems in which there is no mathematization to be done.

Vertical mathematization is on the other hand intimately related to the idea of 'learning strands' or trajectories of learning. In the case of the well known case of long division there is a continuing process of progressive mathematization or schematisation starting from a context. This aspect of a 'model of' a context that can function as a 'model for' for problem solving in other contexts was brought forward by Streefland in 1985 (Van den Heuvel-Panhuizen, 2001, p 4) and Treffers (Treffers, 1991, p 33-34). In fact this was already indicated by Treffers when remarked in the earlier discussions of problem solving with routes and grids that 'through this the first step is set on the long path of model-forming. What serves at first as a problem can later be used as a tool to solve other problems' (Treffers, 1978, p 47). But to function as such a ground for vertical mathematisation, the context has to fulfil stringent criteria. Gravemeijer in elaborating on this aspect makes the very important point that the model of/model for heuristic emerged as a 'result of an effort to come to grips with an effective *design* practice' and not just theoretically. He brought out that in this case what is central is the paradigmatic situation with which children can engage with and detailed out the different levels involved in this process of vertical mathematisation (Gravemeijer, 1997, p 29-32). This vertical aspect of mathematisation that got clarified through practice also meant reassessment of the role that contexts play in mathematics education.

Anchoring Context

For the last ten years or so in our practice we have experienced the power of this form of vertical mathematisation starting from a real context which functions as a paradigm. One has called such contexts as anchoring contexts which has now become a common shared term of the community of teachers with whom we work. When Freudenthal talked of real contexts he meant contexts that are experientially real to the children, taking care to note that even mathematical contexts can function as real to children provided they are that comfortable with them. Such contexts have been designed and used over the years from Grade I to Grade 6 for different topics and a few of them are presented to illustrate some characteristics of the level raisings involved when using such model contexts.

In designing an anchoring context to support vertical mathematisation two important aspects are taken into consideration. First is that children should be able to understand and get engaged with the problem posed and at the same time be able to solve it by some means, whether using concrete material, by counting or by calculating or whatsoever. We have found that stories can play a very important role in designing effective anchoring contexts. Recent experience of teaching children of Grade VI has convinced me that the impact of stories is not confined to the lower primary classes (Menon, 2012).

The second aspect is the adequacy of the situation in bringing forward the key mathematical idea that the teacher or the designer has in mind. Thus for example it was decided to try out a fraction trajectory with unit fractions as the basis. To develop the meaning of denominator a context was designed in which a boy had to choose where he would sit, given a choice of 4 different sharing situations. This was inspired by the pancake sharing context that Streefland had suggested but with a major modification since unit fractions were chosen as the first landmark. The fraction cut-outs play an important role in this trajectory, but over the five years that one has seen the trajectory in use, one has been surprised by the very flexible ways in which these cut-outs could be used. One of the processes of vertical mathematisation that one noticed in this trajectory was the change in the language of the children. To begin with for children, 1/6 meant that 6 *children* were sharing a cake, later they would say that one *cake* is divided into 6 (equal) *parts* and later it becomes one is divided into 6 (equal) parts and later it became a number they could place on the number line.

These anchoring contexts whether they are that of cake sharing for fractions or birds flying out of a tree to find food to introduce addition and subtraction or biscuit packing to introduce factors, one key aspect of the anchoring context is that it anchors the discussions for some time. This is important to induce the focus to shift to numbers from the other aspects of the context. When the context is kept constant then numbers and number relationships start emerging more starkly for the children and they start noticing patterns. In fact we go to other type of contexts usually only after children are able to relate to the symbolic representation. Once this symbolisation is made real to children, then they are able to use it as a tool to deal with other situations.

It is seen that such contexts truly function as 'anchoring contexts', a haven where you return whenever there is a need. Even after children become comfortable with the fraction notation and are able to see it in abstract terms, when new challenges come some of them go back to visualisation of fraction cut-outs to think about the problem. Here we can see that what was earlier only a representation of a situation involving sharing of cakes has now become a generalised tool to think about other fraction operations such as multiplication and division, with the introduction of new (anchoring) contexts. One sees that there are different processes involved in a long-term trajectory involving anchoring contexts and one sees the need for further detailing out of the processes to get a clearer picture of the process of vertical mathematisation.

Currently in mathematics education, one can distinguish two broadly different approaches in the use of contexts – one can be termed a paradigmatic approach and the other an inductive approach in the use of contexts. The first one recognizes the important role that paradigms play in mathematics. Freudenthal in his perceptive statement said, "More often than one tends to believe, generality is achieved by the *aha* experience of one single paradigm only to be reinforced by a few (albeit not necessarily many) more of them" (Freudenthal, 1991, p 35). The other approach of exposing children to many contexts with the implicit understanding that children would generalise across these different contexts is what Treffers had referred to as the empiricistic approach which in the seventies was very dominant in the U.K. (Treffers, 1978, 1991). These two approaches can be diagrammatically represented as shown in Figure 1.

NCERT Textbooks

Since NCF 2005 emphasised mathematisation, it would be useful to consider how this approach is reflected in the textbooks produced since then. The textbooks produced since then form a refreshing set in which contexts play a key role. Textbooks can form a key input into the didactisation process and therefore an analysis of the textbooks can indicate the affordances for mathematisation in the classroom facilitated by the textbook. The NCERT textbook books from Grades 2 to 5 are considered here both in terms of horizontal and vertical mathematisation. A general overview is attempted given the space constraint. In the case of vertical mathematisation division is taken up for consideration.

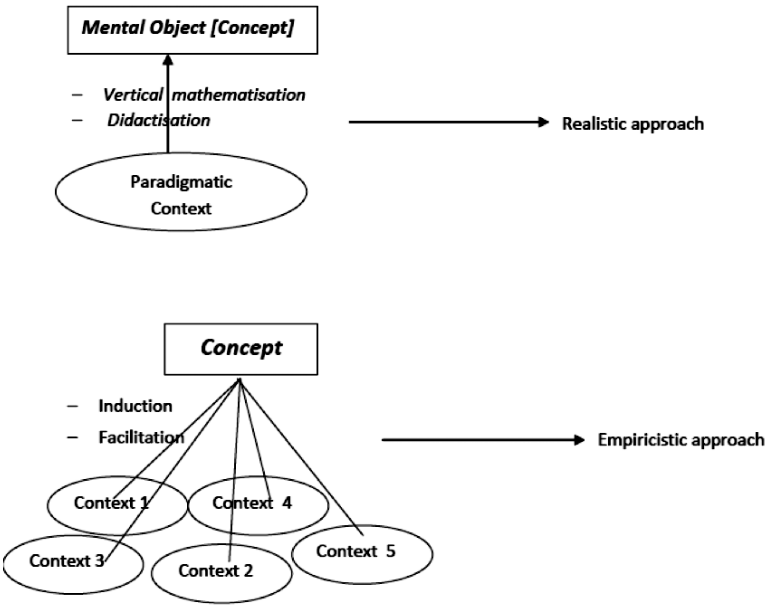

Figure 1. Contexts and Approaches to Mathematics Education

Horizontal Mathematisation

There are quite a few chapters in these books which can be used by teachers to support mathematisation. The chapter 'A Trip to Bhopal' (NCERT 2007, 23-34) of Grade 4 (Book 4) is a good example. The opening of the chapter conveys the excitement of starting on the trip and the question of the number of buses needed is posed very naturally and with all the urgency- provided of course the teacher enacts this in the class, the first page also gives hints about how the teacher could lead the conversation in the class about the 'extra' children and is a good start for prompting children to find their own means to find an answer. Here finding out the number of buses needed has a real purpose. This context is an adaptation of one of the classic RME contexts for division with buses for transporting football supporters – a very nice adaptation appropriate for the Indian context. The introduction of change in the capacity of buses and therefore the need to calculate the number of buses again happens in a very natural way. The calculation of the time needed to reach Bhopal, the impact of stopping over, on the reaching time, and especially the estimation of the width of Narmada and getting a sense of it using the length of the bus provide opportunities for mathematisation. Teachers would also get a good idea of how to give a sense of what 10,000 years mean with the example of using great grandmother's age as a unit.

The strength of the chapter can be considered to lie in the fact that there is a purpose which can make sense to a child embedded in this chapter – there are actually problems to be solved, which is often not the case with many 'integrated' chapters elsewhere where there is only a description and a lot of questions to answer. But the effectivity of any such chapter depends on the manner in which the teacher transacts it in the class.

Yet there are some question marks that arise even with this chapter. It assumes that children are already comfortable with calculating the duration of time and with a sense of what one meter means and preferably also of multiples of 10 and 100.

Vertical Mathematization

I would discuss the issue of vertical mathematisation by focusing on two critical aspects related to the didactisation role of the teacher and therefore also of the textbook – that of providing a concrete orientation and of providing examples and models to support level-raising. The role of 'concrete orientation' is to provide a context and a problem with which children can engage and which they can solve using their informal strategies (See Table 1). Such a concrete orientation context would be one where the purpose for the child in problem solving is not obviously related to the target knowledge. This would be an adidactical situation as defined by Brousseau (2002).

Grade 3 textbook has the first step towards division and here the division symbol is also introduced. It also appears to be based on a different philosophy as compared to the textbooks of Grades 4 and 5. The chapter does not present any situation which calls for problem solving. The 'problems' presented are what can be called as exercises (Schoenfeld, 1992, p 12) and introduces division by following the traditional pattern of worked out example (involving groups of butterflies, caterpillars and laddoos) followed by similar exercises. The only problem solving question is that of rearranging *jalebis* in plates to have equal sharing. The division concept is presented in this chapter through a partitive model. This is then followed by a situation of different animals jumping and then going on to bare number division problems with the hint to use the multiplication table.

Division gets focused in Chapter 'Tables and Shares' (NCERT, 2007, p124-132) in Grade 4. Here four different contexts are taken and each time a different solution method is suggested. In 'Jumping Animals', it is jumping on the number strip to decide how many jumps to reach any particular number. In making necklaces with 'Sea Shells' repeated subtraction is suggested. In 'Gangu's Sweets', a situation is given which could in fact have provided a good orientation basis for division, but it is not presented as such. In 'Children and their Grandfather' the partial quotients method is introduced within a format. In this case also there is not sufficient concretisation of the problem. Thus for example, when grandfather asks 'how to share the money equally among all of you', the discussion starts by one child saying, "we know how to do 70 ÷ 5" and not by saying, you can first give ten rupees to each of us and then....'(p 128). This problem of insufficient concretisation is also followed in Grade 5 where returning the loan taken for a scooter is taken as the context, although it is a context that has a lot of potential for such treatment (p 179). In fact what one finds is a collection of contexts and no paradigmatic context that can support further abbreviation of the strategies as children reflect on their informal strategies.

The textbook suggests to the teachers in a note to allow children to solve these questions using any method of their choice including addition and multiplication. But the textbook has given a privileged position to repeated subtraction and addition is not presented. This can be understood in terms of the connection to the partial quotients method that is aimed at. But our experience with children over the last few years shows that repeated addition rather than subtraction is the main informal strategy that develops. Unfortunately research literature does not seem to distinguish between these two strategies and often club them into the same type (Anghileri et. al. 2002, p 162) and within literature there is some ambiguity about this aspect. In any case, in quotative situations there is evidence for the overwhelming presence of addition and of doubling and multiples of ten in the informal strategies of children.

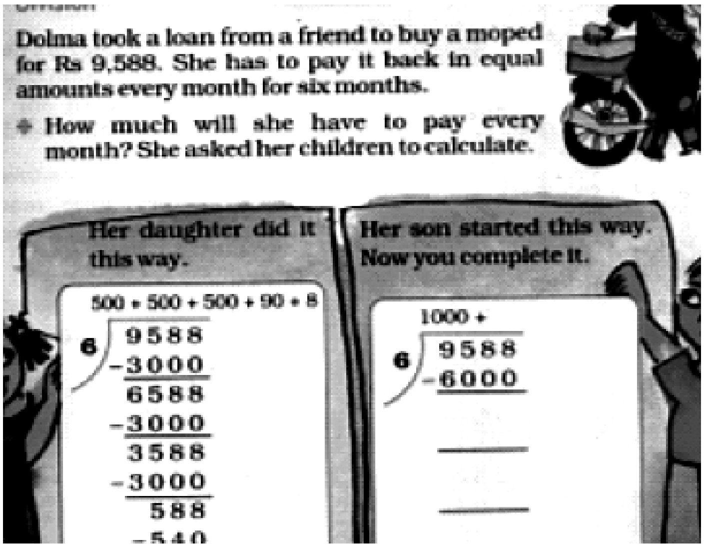

Figure 2. An example from grade 5 involving 9588 ÷ 6

Supporting level-raising of children's methods by steering the discussion and providing examples and models at the appropriate time is another key aspect of supporting vertical mathematisation. We would discuss this aspect with the example of the partial quotients method used in the textbook. The partial quotients method in fact connects to the multiplying-on methods that children tend to use once they are comfortable with multiplication. Otherwise they would most likely use repeated addition. In fact with smaller numbers, multiplying-on is quite an efficient strategy and in case children need to be prompted to go for partial quotients method they need to be prompted by the use of appropriately large numbers. It is true that 'the beauty of this method' is that children in a class can operate at their level of comfort by chunking differently (NCERT, 2007, p 128). But supporting vertical mathematization also means that children's efforts at chunking needs to be supported with well chosen numbers and the development of appropriate subskills, keeping in mind the trajectories for the evolution of the division method.

For example in Grade 5, in the example involving 9588 ÷ 6, (p 179) the two method examples discussed cannot be considered to be aligned to the possible path of development of this trajectory.

Multiplying by 500 is not an expected reaction – it would be either 1000 or 100. A bifurcation can happen after the subtraction of 6000. In this case some children would go for 500 times straight away (by halving 6000) while others who are not so confident would go on subtracting 100 times. An understanding of the actual processes supported by the textbook examples could help the teacher to steer the classroom discussion to support schematisation.

The other aspects of vertical mathematization by providing conflict problems to support reflection and the ensuing generalising is taken care of by some problems in the Grades 4 and 5.

This short review indicates that while there is room for supporting horizontal mathematisation in the new NCERT textbooks, vertical mathematization is not in fact supported. Further analysis of the other topics could throw more light on this.

To Conclude

The distinction made between horizontal and vertical mathematisation is a useful tool that can support curriculum development. Micro-didactical and macro-didactical approaches need to be combined to support longer term development of trajectories and intertwining of learning strands (van den Heuvel-Panhuizen, 2001, p 2). This might also mean a change in the approach to educational reforms, as recently Paul Cobb mentioned about his own experience, "The heuristics on which we had relied were relatively global in nature because we had derived them from a general background theory. In contrast, the specific design heuristics that Treffers outlined had emerged from and yet remained grounded in the activities of designing and experimenting in classrooms." (Cobb et. al, 2008, p 6).

By focusing on contexts, the early reform movements had taken the first step in inverting the 'antididactic inversion' of starting from the product of mathematisation. The review of the reform process needs to orient us towards its further evolution. In a review of the Wiskobas programme Freudenthal himself concluded that in the seventies the programme has spent too much energy on the design of themes and too little on model contexts that could be vertically mathematised. Treffers mentions that integrative themes are important, 'but an overemphasis leads to empiricistic mathematics with too little vertical mathematising (Treffers, 1993, p 94).

The process of connecting with the world, everyday and mathematical, that is real to the children of our country and designing longer-term trajectories based on them would require active and grounded involvement and collaboration of tens if not hundreds of people. The development of a range of trajectories for each topic so as to be able to connect to the lived experiences of different groups of teachers in the country would also be yet another task to be designed.

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Performance of First Year Medical Students in Chemistry

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*Problem statement***:** *Bloom's cognitive Taxonomy is the most popular way to characterize students' learning outcomes. The original taxonomy has since been reviewed to accommodate a much broader audience. The aim of this study was to assess the knowledgebase of medical students in chemistry using pen and paper year end examination. Approach***:** *The model of prior knowledge was used to categorize assessment questions into those requiring declarative and procedural knowledge. Correlation analysis and linear regression analysis were used to assess relationship between overall performances of students with different knowledge components. Results***:** *The results indicated that majority of students are in the declarative knowledge level. Correlations observed showed that the relationship of declarative knowledge, r=0.901 and procedural knowledge components, r=0.790 with overall performance are highly correlated. However, the correlation between declarative knowledge component and procedural knowledge component was moderate, r=0.450. Conclusion/Recommendations***:** *A high correlation was observed among the relationship of declarative knowledge and procedural knowledge with overall performance. Correlation of declarative knowledge with procedural knowledge was positive but weak. Of the two knowledge components declarative knowledge was a more significant predictor of performance than procedural knowledge component. To improve quality of our students, assessment should focus on enhancing students cognitive and affective skills including domain specific knowledge in subject matter domain instead of merely memorizing concepts and principles. Students should be taught how to use acquired knowledge and integrate prior knowledge with new knowledge in a meaningful way.*

Introduction

Assessment is an important aspect of teaching and learning related to the (Holbrook, 2005) used in the evaluation of students' learning process (Richards, 2001). Several studies cited in Scalise *et al*. (2003) revealed that much of the chemistry content currently taught and assessed in terms of facts and algorithm and procedural knowledge has little emphasis on conceptual understanding. Shankar *et al*. (2005) recommended that in learning, students should develop transferable skills important, not only in undergraduate medical education but also for continued learning throughout their medical career. For students to have transferable skills it will require that they should progress from the novice level of understanding to the graduate and expert levels of being innovative.

The Bloom's Cognitive Taxonomy is a domain used widely by psychologists, educationalists and researchers (Forehand, 2005) to assess learning outcomes. The six levels used to categorize the learning are: knowledge, comprehension, application, analysis, synthesis and evaluation (Bloom *et al*., 1956). The taxonomy is a multi-tiered model of classifying thinking according to cognitive levels. In this way it is expected that students who are able to apply knowledge should have an understanding of the relevant concepts.

The original taxonomy has since been reviewed by cognitive psychologists, curriculum theorists and instructional researchers and testing and assessment specialists. The advantage of the revised taxonomy is the inclusion of specific verbs and products linkage with each of the level of the cognitive process dimension. The revised taxonomy can therefore be used for students from the primary level to the tertiary level. Also, the revised version shows the distinction between the different types of knowledge and cognitive processes (Anderson and Kathwohl, 2001). Dochy as cited in Hailikari *et al*. (2007), regard knowledge as comprising of the declarative and procedural knowledge. Dochy defines declarative knowledge as accumulation of facts and concepts which comes to the surface through recognition or reproduction. Procedural knowledge on the other hand is knowledge of application and procedures which comes to the surface in assessment through production or application. In Anderson (1995) declarative knowledge is referred to as "knowing that" and procedural knowledge as "knowing how".

In Hailikari *et al*. (2007) it is recommended that an instrument used to measure learning outcomes objectively should be able to illustrate the level of conceptual understanding of the student. According to Dochy and McDowell in Hailikari *et al*. (2007) assessment of students using the revised taxonomy provide the possibility of exploring an individual's knowledge base on multiple dimensions. Klymkowsky *et al*. (2003) believe that this will enable educators to see the loophole that must be closed in order for students to have conceptual understanding. The purpose of this study was to determine the relationship of performance scores of students in declarative and procedural knowledge on their overall performance score.

Medical students are required to learn basic general and organic chemistry as a prerequisite for medical courses such as physiological chemistry, biochemistry, microbiology, pharmacology and chemical pathology. As a service course for medical students, chemistry aims at enhancing understanding and applicability of scientific concepts relevant in the medical field. For this purpose the teaching strategies and assessment methods used should be able to provide students with an ability to apply acquired knowledge. Observation has shown that senior medical students at University of Limpopo (Medunsa Campus, South Africa) in this study have difficulties in courses requiring basic knowledge of chemistry. This could be influenced by various factors such as attitude towards a subject or lack of relevant prior knowledge or lack of proper understanding. Their knowledge of scientific concepts appear to be isolated facts void of context. Students are able to recall facts but are unable to see their applications in their field of study.

During teaching and learning we often overlook contributions of students' knowledge base as a learning outcome to their future learning. Through this study it is also hoped that lecturers will obtain some guidelines for effective design, development and assessment methods to facilitate teaching for transfer.

Aims and Objectives

During teaching and learning we often overlook the knowledge base of the students as a learning outcome and the effect it has on their future learning. A full commitment to teaching and learning should include assessing and documenting what and how much students are learning and using this to improve the educational experiences being offered.

The aim of the proposed study is: to investigate the relationship between performance of first year medical students at University of Limpopo towards chemistry and their learning outcomes as defined in Hailikari et al. (2007) model of prior knowledge. The study has the following objectives:

- To assess learning outcomes of first year University of Limpopo medical students in chemistry according to modified version of revised Bloom's cognitive Taxonomy designed by Hailikari *et al*. (2007)
- To determine the relationship between first year students' knowledge base and overall performance in chemistry

The results of this study could be used by educators to improve the learning outcomes of students as well as by administrators in monitoring the learning process of students which could help in predicting future learning progress. Program developers could also benefit from this study by using these results as a guide that will help in designing programs and activities that will advance students from one level of knowledge to the other.

Materials and Methods

Study sample

The sample consisted of 122 medical students in a chemistry I class at University of Limpopo (Medunsa campus, South Africa). The sample consisted of females (59) and males (63).

Research design

In the study the learning outcomes of students in chemistry the knowledge acquired during the learning process is assessed. The study design is correlational retrospective ex post facto and involves descriptive analysis.

Data collection methods

Instrument to Measure Student's Learning Outcomes Students' learning outcomes were measured by pen and paper examination which included various questions from chemistry topics. Students' text book, study guides, learning objectives and their previous tests were used in compiling the examination paper. The students' lecturer and the researcher who is also a chemistry lecturer were involved in compiling the examination paper and the scoring guide.

	Declarative knowledge		Procedural knowledge	
Knowledge Components	Knowledge of Facts	Knowledge of Meaning	Integration of Knowledge	Application of Knowledge
Indicators	Recognizing, recalling, remembering	Understanding, Defining, reproducing, meaning of concepts	Understanding concepts and their inter-relations, classifying, and comparing	Problem solving, application of knowledge, producing, and implementing

Applying

Cognitive process

Understanding

Knowing

Figure 1: Hailikari's modified revised bloom's taxonomy

Questions were categorized into those requiring declarative knowledge and those requiring procedural knowledge as described in the Hailikari's model of prior knowledge (Fig. 1). The total mark on the question paper was 75, of which 50.7% was on declarative knowledge questions and 49.3% was on procedural knowledge questions.

Instrument reliability and validity

Lin, in Deratzou (2006) suggests three types of validity; construct validity, internal validity and external validity. It is stated in Deratzou (2006) that multiple sources of evidence are used to ensure construct validity, while triangulation of data, member checking and clarifying investigator bias are employed for internal validity, while external validity implies the generalizability of the data to other population an exercise which is which is usually difficult in qualitative studies (Bogdan and Biklen as cited in Deratzou (2006).

Data analysis

Descriptive analysis method was used to collect data for learning outcomes variables. Qualitative analysis of the results was also used for comparing the performances of students in selected questions. Correlation and linear multiple regression analysis were used for the relationship of overall performance score and performance in declarative and procedural knowledge scores. The responses to the questions for each knowledge category were scored according to the scoring guide using the following codes 0 for any score less than half the mark allocated on the question paper, 0.5 for half the mark allocated on the question paper and 1 for any mark greater than half the mark allocated on the question paper. Code 0 was used to indicate operation at declarative level, 0.5 for operation at procedural level and 1 for operation above procedural level. The overall performance of students in the examination paper will be displayed as the sum of all marks obtained by the student as allocated in the examination paper. All results will be displayed in tables.

Results

The total number of students who wrote the examination was 121. Cronbach alpha coefficient for the learning outcomes instrument was .62 for 25 items. The scores of students in the examination paper are displayed in the Table 1.

				Number of students scoring (%)		
Assessment	Knowledge base	Mean	SD	0	0.5	1
1.1	Declarative knowledge	0.5124	0.39509	36 (29.8)	46 (38.0)	39 (32.2)
1.2a	Declarative knowledge	0.2314	0.41353	90 (74.4)	5 (4.1)	26 (21.5)
1.2b	Declarative knowledge	0.0702	0.23546	111 (91.7)	6 (5.0)	4 (3.3)
1.2c	Declarative knowledge	0.8760	0.33091	13 (10.7)	0 (0)	108 (89.3)
1.3	Declarative knowledge	0.7769	0.35326	13 (10.7)	25 (20.7)	83 (68.6)
1.4	Procedural knowledge	0.1942	0.39461	98 (81)	1 (0.8)	22 (18.2)
1.5a	Declarative knowledge	0.4256	0.45489	52 (43)	27 (22.3)	42 (34.7)
1.5b	Declarative knowledge	0.4050	0.48440	70 (57.9)	4 (3.3)	47 (38.8)
1.5c	Procedural knowledge	0.7645	0.40350	25 (20.7)	8 (6.6)	88 (72.7)

2.1a	Declarative knowledge	0.5207	0.46752	52 (43.0)	14 (11.6)	55 (45.4)
2.1b	Declarative knowledge	0.3223	0.46485	81 (66.9)	2 (1.7)	38 (31.4)
2.2a	Procedural knowledge	0.5785	0.46551	44 (36.4)	14 (11.6)	63 (52.1)
2.2b	Declarative knowledge	0.4050	0.49293	72 (59.5)	0 (0)	49 (40.5)
2.2c	Procedural knowledge	0.8554	0.34423	16 (13.2)	3 (2.5)	102 (84.3)
2.3	Procedural knowledge	0.0124	0.10130	119 (98.3)	1 (0.8)	1 (0.8)
2.4a-c	Declarative knowledge	0.6322	0.42214	31 (25.6)	27 (22.3)	63 (52.1)
2.4d	Declarative knowledge	0.3099	0.44841	80 (66.1)	7 (5.8)	34 (28.1)
3.1a	Procedural knowledge	0.3554	0.40020	61 (50.4)	34 (28.1)	26 (21.5)
3.1b	Procedural knowledge	0.8182	0.38730	15 (12.4)	0 (0)	106 (87.6)
3.1c	Declarative knowledge	0.7521	0.43361	22 (18.2)	0 (0)	99 (81.8)
3.2	Procedural knowledge	0.2769	0.41808	88 (72.7)	13 (10.7)	20 (16.5)
3.3a	Declarative knowledge	0.7190	0.45135	6 (5.0)	0 (0)	115 (95.0)
3.3b	Declarative knowledge	0.7438	0.43835	16 (13.2)	14 (11.6)	91 (75.2)
3.3c	Declarative knowledge	0.6074	0.47525	43 (35.5)	7 (5.8)	71 (58.7)
3.4	Procedural knowledge	0.4174	0.48882	62 (51.2)	11 (9.1)	48 (39.7)

Table 1: Scores of students' learning outcomes.

Correlations observed among overall performance of students in chemistry and performance in different knowledge components are illustrated in Table 2. Pearson's correlation for the relationship of declarative knowledge component with overall performance was r=0.901, and for the relationship between procedural knowledge component and overall performance it was r=0.790.

Linear multiple regression analysis

The standardized regression coefficient are displayed in Table 3, for declarative knowledge the value was 1.002 and 0.990

for procedural knowledge component with F = 19511.226, p = 0.000.

Variable	Overall performance	Declarative	Procedural
Overall performance	1.000	0.901*	0.790
Declarative	0.901*	1.000	0.450*
Procedural	0.790*	0.450*	1.000

*P<0.01

Table 2: Correlations between overall performances in chemistry with performance in different knowledge components

Explanatory variables	N=103 B	SEB	Beta	t	sig
Overall performance	0.213	0.216	-	0.810	0.418
Declarative	1.002	0.008	0.684	120.893 0.000	
Procedural	0.990	0.012	0.482	85.116	0.000

Table 3: Summary of regression analysis: Different knowledge components predicting overall score

Results of questions selected for qualitative analysis

There were 89.3% students who were able to answer1.2 c while only 3.3% were able to answer 1.2b. In question 2.4 a-c, 52.1% of the students were able to obtain more than half of the total mark allocated and only 28.1% were able to obtain at least half of the allocated mark to question 2.4 d. In question 3.1c, 81.8% of students were able to state the required law, but only 21.5% were able to realize the deviation of the given experimental results from the law. Question 3.1 b required students to calculate the volume of a gas when pressure was decreased, given a set of initial volume and pressure at constant temperature. In this question 87.6% of students obtained more than half the allocated mark. In question 2.2b students were asked whether the pH value of a stomach acid will increase, stays the same or decrease after taking a dose of $Mg(OH)2$ and in this question 52.1% were able to give the correct answer.

Discussion

From Table 1, the highest mean score was in a question requiring declarative knowledge. In this question, majority of students obtained a mark of more than half the total score allocated. The lowest mean score was on a question requiring procedural knowledge where almost all students obtained a mark that is less than half the mark allocated to that question. The results of the performance of students revealed that students have obtained more than half the allocated mark in most questions requiring declarative knowledge.

Correlation for the declarative knowledge component with overall performance was positive and high, and for procedural knowledge component and overall performance it was also positive but moderate. The ANOVA results indicated that there is a positive significant relationship between the overall performance of students and the two knowledge components, with the declarative knowledge component being a better predictor of the overall performance than the procedural knowledge component.

Discussion of qualitative results

The fact that majority of students were able to answer question 1.2b but not 1.2c despite their similarities could mean that the students are unable to classify and compare. The impression that one gets from this observation is that students might have remembered the second question from previous lessons but were unable to associate it with the first question, the “per kilogram” also could have been a problem since this value was stated in words and not in numbers as in the second question.

In questions 2.4 a-c and 2.4 d, students had an option of recalling familiar names or analyzing the formulas using rules for naming inorganic compounds. Students who used the rules for naming these compounds are expected to be able to know what each number in the formula of a substance represents. Students who were able to name the compounds but did not know what the numbers used in the names are representing are assumed to have relied on remembering such names from the past. Since that was a greater proportion of students who were able to name the compounds but did not know what the symbols in the formulas of the names mean one could conclude that students had encountered these formulas before and could recall their names.

The fact that this large number of students could only state the law in question 3 but were unable to interpret the experimental data relating to the law could imply that students resorted to reproduction of the statement of the law without understanding its meaning or their inability of interpreting experimental results. However if students were operating at a higher cognitive level they would have realized the inconsistency of the law and the given experimental data.

In answering question 3.1c students who understood what the law was implying and who reflected on what they were doing would have realized from the values of the two variables (volume and pressure) initially and finally that the increase in pressure is related to the decrease of volume of the gas. This would have enabled them to make the necessary correction to their mistake in question 3.1b.

It was surprising to discover that from student’s previous assessment all students stated that “the lower the pH value of an acid the stronger is that acid”. However when they were asked whether a basic substance will decrease or increase the pH value of an acid majority of the students said the value will decrease. Their response indicated that students are not really thinking about what they are writing. What could be concluded from the quantitative and qualitative analysis of these results is that majority of students lack understanding and do not reflect on what they are doing. This behaviour is usually associated with students who operate at a lower level of cognition and are therefore on the declarative level of cognition.

Conclusion

The responses of students in individual questions have revealed that students have knowledge but they are unable to use acquired knowledge in appropriate situations. The conclusion that could be made about the above results is that students resort to memorization of facts and procedures without understanding concepts. The performance of students indicated lack of analytical reasoning which according to Kitchen *et al*. (2003) is not possible unless assessment specifically designed to foster it are employed. It is therefore recommended that assessment should be used as a strategy that is able to move the knowledgebase of students from the novice level to the expert level. Wiggins and Mc Tighe in Tanner and Allen (2005) assert that students will be able to explain, interpret and apply acquired knowledge only if they understand.

In the study of Hailikari *et al*. (2007) it was shown that the type of knowledge makes a difference in the overall performance of the students. However, it was also shown that measures assessing procedural knowledge were able to predict final grades while those measuring declarative knowledge did not predict final grades, the opposite was obtained in the current study. The results of this study can be justified by noting that students have to first recall relevant information before they can apply, analyze or integrate knowledge. To learn to transfer it is recommended that assessment should include all knowledge levels. To improve quality of our students, assessment should focus on enhancing students cognitive level instead of merely encouraging them to memorize concepts and principles. Students should be taught how to use acquired knowledge and integrate prior knowledge with new knowledge in a meaningful way. Shankar *et al*. (2005) recommended that in learning, students should develop transferable skills which are important, not only in undergraduate medical education but also for continued learning throughout their medical career. For students to have transferable skills it will require that they should progress from the novice level of understanding to the graduate and expert levels of being innovative.

According to Tan (1992) high level conceptual understanding of students will enable them to integrate the basic and clinical sciences which are required in higher levels. Students who are only able to recall the stored knowledge will therefore have difficulties in applying that knowledge in appropriate situations.

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Integration in Science Education: Trans-disciplinary Inquiry and Conceptual Infrastructures

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Educational circles take it for granted that science education should help learners achieve an integrated understanding of information (data points) within a field of study. Such integration calls for the specification of correlational and causal generalizations in the curriculum, which are then integrated through scientific theories. Less recognized, perhaps, is the need for integration across fields: trans-disciplinary integration. This paper attempts to make a case for trans-disciplinary integration along the dimensions of ontology and epistemology, and provides an illustrative sample of a high school curriculum (specification of desired learning outcomes) along both these dimensions.

Integration by the Human Brain and Science

The human brain has an extraordinary capacity to convert sensory and non-sensory stimuli, or 'data points', into sensations and sense perceptions, and integrate those experience-fragments into structures that we call 'knowledge' of the external world. It is these structures that allow us to make sense of our experience; and they guide our choices of action. A great deal of such integrative construction of knowledge takes place below the level of consciousness. The 'data' recorded by the retina, a biological instrument, for instance, are automatically integrated, and interpreted as objects in the external world.

Scientific inquiry can be thought of as a self-conscious and systematic extension of the brain's predisposition for such integration, taking place at the levels of both the individual scientist and the scientific community.

If I had to pick one single goal of science education as the one with greatest value for all students (whether future scientists, science professionals, or individuals who may not need any specialized scientific knowledge in their professional lives), it would be the ability to engage in the modes of integration that are characteristic of scientific inquiry.

In what follows, I explore four levels of such integration: descriptive-phenomenological, explanatory-theoretical, ontological, and epistemological. A framework of this kind, I believe, has the potential to meaningfully guide decisions on science curricula, classroom activities, learning materials, and assessment tasks.

Integrating Experience-Fragments (Descriptive-Phenomenological)

An experience that human beings everywhere and through all times integrate is the following observational generalization about day and night:

Night follows day and day follows night.

This generalization does not require any conscious or systematic observation, let alone scientific inquiry. But it integrates as part of our commonsense knowledge the data points that are fragments of our experience of day and of night. For people living near the equator, day and night are approximately equally divided, so that each data point has the same duration. For observers away from the equator, such data points would involve unequal durations of day and night. A careful documentation of these data points reveals the following observational generalizations:

The total duration of each day-night pair is constant.

There is a stretch of time in which the relative duration of nights increases (the duration of days decreasing correspondingly), followed by a stretch of time in which it gradually decreases (the duration of days increasing), completing a cycle in 365 day-night pairs.

Each of the three observational generalizations above connects and integrates three different collections of data 'fragments' into a pattern. They are accompanied by further integration of experience fragments such as the following:

The locations of sunrise and sunset for each day-night pair shift from north to south and back, completing a cycle in 365 day-night pairs.

The (mean) temperature during the day-night pairs gradually increases and then gradually decreases, completing a cycle in 365 day-night pairs.

These generalizations integrate experiences of phenomena on earth. Of these, the experiences of sunrise and sunset are associated with an entity in the sky that we call the sun.

Turning our attention to experiences of phenomena in the sky, we see a set of shining dots in the night sky that we call stars or planets, and a shining circular disc that we call the moon. At the phenomenological or descriptive level, the observational regularities in these night sky dots can be stated as follows:

The relative positions of the bright dots in the night sky (which we call 'stars') do not change with respect to one another. The positions do change in the case a handful of dots (which we call 'planets').

In relation to the earth, the overall orientation of the dot configuration undergoes a continuous change through each night; this can be described as a movement of the dots along a circular arc around a central dot (which we call a 'pole star').

If we take the configuration of 'stars' as our reference point, the 'planets' appear to move in a given direction for several days at a stretch, then reverse direction (called 'retrograde motion') and then go back to the original direction.

These observational generalizations can be thought of as observational/phenomenological laws. In stating these laws, we are expressing the regularities as we experience them, without making any claims about the deeper reality that underlies these experiences.

The very first step in learning science is to develop the capacity to notice such regularities in our experience of nature, to formulate them clearly and explicitly, and to make systematic observations to test them, such that they are validated as correct, or rejected as flawed. This is the essence of ***observational science*** (including experimental science).

Integrating Observational Generalizations (Explanatory-Theoretical)

Our observational laws integrate fragments of our experience. But they do not help us *understand* the external reality that underlies our experience. Is it simply chance that the same number, 365, appears in three different observed cycles? It is logically possible that one cycle is 365, another is 400, and yet another 52. Is there a deeper reason for why they coincide? Also, why do the relative durations of day and night vary more and more as we move away from the equator? Could it have been the other way round? And given the variation in the relative durations of day and night, why is the duration of the day-night cycle a constant?

Likewise, we notice two further cycles of apparent movement: those of the sun from east to west in the day, and the stars around the pole star at night. Why do these two cycles coincide? Could it have been different, say, the sun cycle being twice the duration, or half the duration, of the star cycle? Could the cycles have been entirely uncorrelated?

Such questions demand that we approach these phenomena as clues to something deeper, and search for that deeper reality. Take, for instance, the 'bright dots' in the night sky. At the deeper level, we can interpret the bright dots in at least two ways. One is as bright objects against a dark background, like fireflies in a dark room. The other is as holes in a dark screen, say, in front of a celestial brightness, like holes in a black umbrella opened on a sunny day.

Having chosen how to represent our perceptual experiences in terms of such deeper *entities*, we also have to choose how to represent *relations* and *processes*. We may, for instance, interpret the perceived movement of the dots as resulting from the celestial entities moving around a stationary earth, as the earth moving around stationary celestial entities, or as some combination of the two. Conceptualizing perceptual experiences in terms of such entities, relations, and processes is the beginning of theoretical integration. To use Plato's metaphor of caves, what we perceive through our senses or instruments are shadows; from these shadows, we must make inferences about a reality that is not accessible to direction perception.

Our observational generalizations integrate data points in our experience of phenomena. The next step in scientific inquiry is to integrate our generalizations as entities, relations, and processes of a reality underlying the phenomena, through explanations. The heliocentric theory of the solar system, and Kepler's laws of planetary motion within that theory are classic example of such integration of observational generalizations.

In a completely different domain of data points, we have Galileo's integration of the observational laws governing the simple pendulum on the one hand and falling bodies on the other. We also have Newton's theoretical integration of gravity and motion in terms of the concept of gravitational force, unifying the observational laws governing the apparent motion of heavenly bodies (Kepler) and the motion of bodies on earth (Galileo).

Likewise, the data points integrated by the theories of magnetism, electricity, and optics exhibit unexpected family resemblances. Such family resemblances call for an explanation. Maxwell's laws of electromagnetism provide a unified explanation for these apparently unrelated experiential phenomena, achieving the integration of the laws in the three domains.

Before proceeding, let me remark that science education has the responsibility to help students develop the capacity for such theoretical integration. This cannot happen without providing space in the curriculum for deep reflection, contemplation, imagination, and rigorous reasoning, along with some mathematical modeling and mathematical calculations.

Integrating Scientific Theories: Trans-Disciplinary Ontology

Beyond theoretical integration lies a more abstract level of integration, that of theoretical concepts and propositions that cut across disciplinary boundaries (as well as across discipline-internal boundaries between sub-disciplines). Such trans-disciplinary concepts and propositions enter into the very development of theories in particular disciplines, connecting and integrating what would otherwise remain fragmented. These concepts and propositions do not directly yield theories that predict data points or even observational generalizations. But they provide the infrastructure that guides our observations and shapes the theories that explain them. They form a *trans-disciplinary ontology* that constitutes an infrastructure on which scientific knowledge and inquiry are built.

For instance, consider the following concepts that we are all familiar with the following: system, structure, function, organization, unit, atomic unit, dynamical system, complex system, complex adaptive system, set, population, category, regularity, probability, randomness, correlation, causation, trait, variable, variation, invariance and variability, change, origin, evolution, development, history…

The scope of the concepts of atom and electron is restricted to physics, but the scope of the concepts of unit and atomic unit extend to most scientific disciplines. The origin of life and the evolution of biological species are part of biology, but the concepts of origin and evolution cut across disciplinary boundaries (origin and evolution of the universe, origin and evolution of the solar system, origin and evolution of the earth, origin and evolution of human language, origin and evolution of capitalism…). These are what we mean by trans-disciplinary concepts.

Why should we be concerned with trans-disciplinary concepts? Because they constitute the foundations for discipline-specific knowledge and inquiry. Take, for instance, the terms 'system', 'structure', and 'function' that students are exposed to in biological, mental, and societal sciences.[1] System and structure appear in the physical sciences as well. What concepts do these terms refer to? Suppose we define them as follows:

> An ***organization*** is an entity that has a structure, system(s) and function(s).
>
> A ***structure*** is a set of entities interconnected through part-whole relations, supplemented by other relations such as ordering, dependence, and correspondence.
>
> A ***system*** is a set of interacting entities, typically performing a set of functions.
>
> The ***function*** of a system or structure is what it does in its environment.

Given these definitions, it follows that a trans-disciplinary theory of organization would include trans-disciplinary theories of structure, system, and function. An organization in this sense could be a business organization, an educational organization, a government organization, an organism, an organ within an organism,

1 This remark warrants three brief notes on the use of the terms physical, biological, mental, and societal. First, if the term 'physical sciences' refers to a cluster of scientific disciplines dealing with physical phenomena (astronomy, physics, chemistry, earth sciences…), there is no reason why the corresponding term 'biological sciences' should not refer to a cluster of scientific disciplines that deal with the phenomena of life. 'Biology', then, is not a single discipline. Second, by the same token, the term 'mental sciences' should include the study of not only the human mind (psychology), but also the chimpanzee mind, the drosophila mind, and so on. The term 'societal sciences' should include the study not only of human societies, but also of chimpanzee, bird, ant, and bacterial societies. This means that the current fragmentation of the study of brain-mind-society-behavior into 'biology' on the one hand, and 'social sciences' on the other, cannot be maintained. We might, of course, view 'human sciences' as a specialization that cuts across biological, mental, and societal sciences, exploring the question what makes us human. Third, engineering, technology, and medicine would then come under applied sciences within the physical, biological, mental, and societal sciences.

a cell, a sculpture piece, a poem, or a motorcycle. In contrast, galaxies, star-planet systems, crystals, molecules, and atoms may not have the dimension that we recognize as function, in which case we would not treat them as organizations.

Trans-disciplinary theories of systems already exist. Bertalanffy's General Systems theory, the theory of dynamical systems (e.g., clock work systems, cybernetic systems), Complex Adaptive Systems (learning and evolving systems), and the like are attempts to study the nature of systems. What science needs next are theories of structure and function, and a general theory of organization that includes all these.

To take a more specific example of trans-disciplinary ontology, and connect it to discipline-specific concepts, consider the study of skin in biology. The skin is composed of layers of cells that cover a large mass of cells in a multi-cellular organism. It is also a sense organ. If we compare the skin with geopolitical borders demarcated by lines in a world map, we see that they are very different entities whose studies belong to completely different disciplines, namely, multi-cellular biology and geopolitics. But suppose we shift our perspective and view skin and national borders as *equivalent*. Suppose we say that skin and national borders are both boundaries, and the object of our study is boundaries. The obvious question then is, "What is 'boundary' such that skin and national borders are both boundaries?" When we pursue this question, it becomes obvious that there are other entities that are instantiations of boundaries, for instance, cellular membranes, fences, and walls.

If we treat skin, national border, cell membrane, fence, and wall as unrelated entities, we would define each concept to suit discipline-specific purposes, and pursue research that does not require biologists, political scientists, and architects to collaborate, or to understand each other. In contrast, studying the shared characteristics of boundaries requires trans-disciplinary perception and thinking, and would result in integration across disciplinary boundaries.

If we contemplate what is shared across the cell membrane, skin, wall, fence, and national border, what emerges is a view of 'boundary' as a mechanism to separate members of a set from non-members, keep the members connected together and provide unity. If we take this function as a defining feature of 'boundary', then the socio-cultural perceptions of us-and-them are also results of boundaries, and in turn, result in boundaries.

Now, consider an assertion like the following: *The us-and-them attitudes of human communities are also found in non-human animals, and even in bacteria and immune cells; it is a manifestation of the same concept of boundary that is seen in national borders, skin, and cell membrane.* This statement may not make much sense from within a discipline-internal perspective. But a trans-disciplinary perspective would allow us to see both what is shared across the different instantiations of the concept, as well as what is significantly distinctive about each of them, and provide the foundations for a general theory of boundaries.

Likewise, a trans-disciplinary perspective allows us to see the unity of the concepts of mind and consciousness currently fragmented as:

- human mind and consciousness, studied as 'psychology' within 'social sciences', and
- animal mind and consciousness, studied as 'biology' within 'natural sciences'.

Similarly, a trans-disciplinary perspective allows us to see the unity of human society studied under sociology, and animal society studied under biology.

Let me turn to a different domain. The terms *point, line, dimension,* and *space* conjure up the world of Euclidean geometry. If we are locked into this world, it would be hard to understand how a line drawn on the surface of a sphere can be a straight line. But if we move to a higher level of abstraction and define a line-segment as the shortest path between two points, we can visualize straight lines not only on flat surfaces but also on curved surfaces.

Abstracting further, consider the concepts of 'point', 'line', 'dimension', and 'space' in geometry and statistics. In geometry, we can say either that a line is composed of points or that a point is an intersection between two (or more) lines. The three vertices of a triangle then are points in a two-dimensional Euclidean or Riemannian space. In statistics, a 'data point' is a set of attributes of an entity along relevant parameters. The statement that Zeno is five feet seven inches tall, weighs 50 pounds, is a Martian, is male, and is 98 years old becomes a (data) point in a five-dimensional space. If so, the statement that there is a correlation between height and age in the human population becomes a statement about a line in a two dimensional space of height and age. A correlation in statistics, in other words, is the analogue of a line in geometry. Once we perceive such equivalences/analogues, the more abstract concepts of point, line, dimension, and space become trans-disciplinary concepts, transcending geometry and statistics.

Consider two squares of length 5 cm. The relation between them is that of *congruence*. The relation between two congruent shapes on a two dimensional flat surface is captured in terms of the transformations of translation, rotation, and reflection. Now consider a 5 cm square and an 8 cm square. The relation between them is that of the mathematical concept of *similarity*, captured in terms of the transformation of enlargement/reduction. Now consider a parallelogram, a rectangle, and a square. They are all quadrilaterals, related through the transformations of shearing or compression. A triangle, a quadrilateral, a pentagon, and a hexagon are all polygons. A polygon and an ellipse (including a circle) are both closed shapes. In terms of rubber sheet topology, a polygon and an ellipse are invariant under the transformation of deformation. A mug and a doughnut also count as the 'same' object because they are invariant under deformation. The kind of thinking we are pursuing in exploring such *analogues* and *abstractions* is the geometry-internal equivalent of trans-disciplinary thinking.

From a trans-disciplinary perspective, what we call homology, analogy, homomorphism, polymorphism, allomorphy, and alleles are the same — in the sense that I am the same person today that I was two weeks ago, and in the sense that a face viewed from two different angles is the same face, without claiming identity. The essential structure of analogy in these concepts also manifests itself in the concept of variations of the same theme: transformation and symmetry in mathematics, archetypes in Jungian psychology, leitmotif in music, and metaphors in poetry.

Trans-disciplinarity, in other words, is itself a manifestation of the creative and integrative faculty of the human mind: a combination of the power of analogical thinking and abstraction. It allows us to make connections across apparently different or even unrelated entities and processes, integrate them, and see unity in apparent diversity, facilitating creativity and cross-pollination. This is what the English poet Coleridge called esemplastic imagination, "bringing together or able to bring together different concepts and thoughts into a unified whole: the esemplastic ability of the imagination." (http://www.yourdictionary.com/esemplastic)

Accepting trans-disciplinary ontology as a valuable foundation for building discipline-specific knowledge, and trans-disciplinary perception and thinking as valuable goals of science education, implies two commitments on the part of science educators. One is to jointly develop a trans-disciplinary infrastructure such that discipline-specific concepts, where relevant, can find a place as special instances of the concepts of trans-disciplinary ontology. The other is to nurture the capacity for the mode of *analogy-based abstraction*.

Integrating Ways of Knowing: Trans-disciplinary Epistemology

In the above section, we looked at the trans-disciplinary conceptual structures that underlie our knowledge of the world: the entities, sets, processes, relations, correlations, causes, structures, systems, and so on that inhabit it. Parallel to these ontological concepts are a set of trans-disciplinary epistemological concepts that underlie our shared ways of knowing: abstract concepts about how we investigate the world, not what exists in the world *per se*.

Students of all academic disciplines are exposed to the concepts of *theories* and *interpretations*, and to the concept of *justification* under the terminology of *proof*, *argumentation*, or *evidence*. Students of all science disciplines are exposed, in addition, to the concepts of *definitions, laws, hypotheses, experiments, observations,* and *calculations.* Of these concepts, definitions are relevant for students of mathematics and analytic philosophy as well. Students specializing in mathematics are exposed also to the concepts of *conjectures, theorems, axioms,* and *lemmas*.

The justification of mathematical conclusions is called a *proof,* while its counterpart in science is *evidence*. A closer look at the concept of justification reveals a structure of *grounds*, *reasoning*, and *conclusions*. In mathematical inquiry, the propositions we wish to justify (*knowledge claims*) are *conjectures*, and once justified, they become *theorems*. Their counterparts in scientific inquiry are *hypotheses* and *theoretical proposals*. The grounds for justification in scientific inquiry are *data (points)* or *observations*; in mathematical inquiry they are *axioms, definitions* and previously established theorems. The mode of reasoning used for the justification in mathematical inquiry is that of *classical deduction*. Scientific inquiry allows for a wider range of reasoning, including *probabilistic deduction, defeasible deduction, induction, abduction* and *speculative deduction*.

These are some of the concepts of the infrastructure of epistemic concepts that underlie scientific and mathematical inquiries. Typically, these foundational concepts are not part of curricula at any level, and their understanding is not tested in any examination. I would like to suggest that a curriculum that aims at the integration not only of knowledge but also of inquiry take these epistemic concepts seriously in the design of curricula, learning materials, classroom activities, and assessment.

Why should we include inquiry in curricula? Because it is valuable in itself, and is the foundation for research. That it is important for graduate students to acquire the ability to engage in independent research is widely accepted in most parts of the world. More recently, there is also awareness among researchers, educators, and educationists that research abilities are crucial right from the undergraduate level, and perhaps even among high school students.

While this awareness is indeed welcome, several questions arise in providing 'research training' to high school and college students:

- Only very few high school and college students go on to become professional researchers. For those who don't, what would be the value of learning research skills?
- Research demands that its outcome be a contribution to the collective pool of knowledge. What are the chances of high school and college students making an original contribution without mastering the state-of-the-art knowledge of the field?
- How can high school and college teachers, mostly not researchers themselves, teach students how to do research?

Perhaps it would be useful to re-evaluate the idea of teaching research skills at high school and college. What is worthwhile in this enterprise is the goal of helping high school and college students to develop the capacity to think and inquire like a mathematician, a theoretical scientist, an experimental scientist, or a philosopher. I would like to suggest that what we should aim at in school and college education is not discipline-specific specialized *research* skills, but the broad spectrum of *inquiry* abilities that cut across disciplinary boundaries. These would then serve as the foundations for future research, while being of value to all those who choose not to follow the path of academic research as a profession.

How to extract the DNA strands from a bunch of cells, how to operate the X-ray crystallography machine, how to use a sound spectroscope, how to design an fMRI experiment, etc., are highly specialized research skills that are hardly necessary for the majority of students who graduate from high school or college. However, how to gather, process, and interpret quantitative data, how to look for an answer to a question, how to design an experiment to test a hypothesis, how to justify or refute a claim, how to critically evaluate a conclusion and the justification that supports a conclusion, how to construct and evaluate a theory or theoretical interpretation, and so on, are important inquiry abilities that are valuable to all high school and college students regardless of their specialization.

In other words, what I am suggesting is that it is important for all high school and college students to develop not only an appreciation of the ways of knowing that result in academic knowledge, but also a rudimentary capacity to engage in those ways of knowing, in an integrated trans-disciplinary manner. Integration comes not only in the understanding of scientific (and other) epistemologies, but also in their practice. The understanding, abilities, habits of thought, and mindset that result from such an education would act as the *foundations* for thinking and inquiry in (a) research, (b) professional spheres, and (c) enlightened and responsible citizenry needed for participation in democratic processes in public spheres.

Integrated Inquiry-Oriented Science Education: A Tentative Curriculum

If we were to accept the broad thrust, if not the details, of the preceding sections, what would the implications be for curricula, learning materials, classroom activities, and assessment tasks? I give below is what might be viewed as a (tentative/incomplete/initial) structured checklist to consider for the design of a science curriculum that pays attention not only to the understanding of scientific knowledge but also to the abilities and habits of scientific inquiry, and from not only a discipline-internal perspective but also a trans-disciplinary one.

Understanding of

- discipline-specific knowledge concepts and knowledge propositions;
- justification (evidence/arguments) for or against these concepts and propositions;
- trans-disciplinary concepts that constitute the infrastructure of knowledge; and
- trans-disciplinary concepts that constitute the infrastructure of inquiry.

Ability to

- apply the discipline specific knowledge concepts to particular problems and situations;
- engage in trans-disciplinary inquiry, drawing on the trans-disciplinary concepts; and
- engage in discipline-specific inquiry and research, drawing on the capacity for trans-disciplinary inquiry-ontology-epistemology as the foundation.

Components of the capacity to engage in trans-disciplinary inquiry would include:

Observational science: ability to

- observe/perceive what an untrained mind may not; notice interesting patterns in what one observes/perceives; formulate observational conjectures on the basis of preliminary observations;
- come up with designs to gather systematic evidence/data to test correlational and causal conjectures; execute the designs; gather and process data; and arrive at conclusions on the correctness of the conjectures.

Theoretical science: ability to

- identify correlational/causal generalizations that call for theoretical explanations; arrive at theoretical explanations; formulate the propositions of a theory with clarity and precision; deduce the predictions of the theory; design observational/experimental schemes to test the predictions;
- check for logical consistency within and across theories; look for and choose between alternative theories.

Justification: ability to

- provide evidence and/or arguments advanced in support of or against a conclusion; and participate in rational debates.

Critical thinking: ability to

- critically evaluate conclusions on the basis of relevant considerations above and beyond the evidence and/or arguments presented in support of or against the conclusions.

Interdisciplinary Approach: Implications in Biology Teacher Education Curriculum

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Interdisciplinary modalities are indispensible for advancement of the school curriculum. A research study has been carried out to compare the need and impact of interdisciplinary approach in teacher education curriculum with special reference to biology education. Without basic concepts of physics and mathematics, a number of misconception and insecure knowledge are found to be prevailing among pre-service biology teachers and practising biology teachers.

Introduction

It is known that teachers usually tend to teach in a manner in which they were taught. Hence, teacher preparatory programmes are quite indispensible for quality assurance in school education. To make secondary level science teachers aware of the holistic nature of science, the pre-service teacher training curriculum need to be designed as carefully as school curriculum. In recent years more emphasis has been placed on conceptual learning and understanding in science (NCF, 2005). Therefore, interdisciplinary approach to science has become a key concept to the advancement of school curriculum (Ortiz, 2006 and Wegmann, 2001). Secondary level science teachers in general are supposed to be flexible enough to integrate the queries of students which are sometime critically drawn upon two or more disciplines. The interdisciplinary modalities synthesizes more than one discipline and creates team of teachers and students that enrich overall educational experience. In recent years biology education research has emerged as a potential field to understand the teaching learning theories derived from a constructivist view of learning (Calik, et al, 2010).

Biology in particular is very often integrated with physics, chemistry and mathematics. Hence, secondary level biology teachers keep equal interest in physics; chemistry and mathematics to teach effectively those topics where above mentioned concepts are bound to be used. Because of the categorization of secondary level science teachers in most Indian schools nowadays, biology teachers are solely responsible for transaction of life-science based topics. Therefore, for strengthening the competency of biology teachers, it is imperative to integrate particularly those concepts of physics and mathematics which are very often used to explain some life-science phenomena (Onellette, 2003). It seems bioscience pedagogy has not kept pace with the revolution that is taking place in science. New disciplines like molecular biology, biotechnology, nanotechnology, environmental science, immunology etc are few examples where good background of physics, chemistry and mathematics is highly essential for effective knowledge organisation.

A good amount of research particularly in biology education is essential to strengthen the curricular reform exercise both for pre-service teacher training programme and school curriculum. Even National Curriculum Framework – 2005 (NCERT) has suggested a balance between the science process skills and science content knowledge, following student centred pedagogy embedded within the constructivists paradigm towards science teaching and learning.

This paper looks into interdisciplinary aspects of teacher training curriculum and the establishment of logical connectivity especially in the context of biological science. Recently, in our integrated B.Sc.B.Ed. programme, we have introduced one paper of physics and one paper of mathematics in biology curriculum. To study the attitude of student teachers towards interdisciplinary approach for better comprehension of life processes, we conducted a detailed research on them. We have also studied the same approach on other batches of integrated students with old curriculum. We compared our research results of two curricula with the approach of practising senior secondary and secondary level biology teachers of different schools.

Methodology

(i) Test design

The diagnostic test comprises of four questions on basic life science (related to heart) where basic physics and mathematics knowledge is equally essential for effective comprehension of the schedule concepts.

Before administration, the questions were ratified by the faculty of physics, life science and education of Regional Institute of Education (NCERT), Bhubaneswar. The questions were also discussed with the medical doctors of the institute dispensary as it involves some medical and health procedure. The concepts taken for the present study have been so selected that these concepts starts from class IX – X science syllabus of CBSE (NCERT text books) and later are carried over to senior secondary biology syllabus, B.Sc.B.Ed. and M.Sc.Ed (Life Science) syllabus of our teacher preparatory curriculum. In 2010, Regional Institute of Education, Bhubaneswar restructured its B.Sc.B.Ed. and M.Sc.Ed. (Life Science) syllabus/and curriculum in which under-graduate student teachers of biological science are ought to take one semester paper on physics and mathematics and post-graduate student teachers (Life Science) have a full paper on biophysics. To study the impact of interdisciplinary approach of curriculum on comprehension skill of student teachers and also to compare it with the understanding of student teachers with general syllabus, such study has been undertaken. Moreover, to understand the importance of physics and numerical calculation in the process of biology teaching, the study was designed with the focus group of pre-service student teachers. First three questions are structured to study the impact of across curriculum or interdisciplinary approach and the fourth question is designed to study the effective teaching skill of biology.

(ii) Subjects

The test was administered to twenty student teachers of M.Sc.Ed. curriculum, forty seven pre-service teachers of new interdisciplinary or across curriculum (B.Sc.B.Ed. semester IV), seventeen pre-service student teachers of old traditional undergraduate curriculum and eight practising teachers of city based schools. The pre-service student teachers of all three curricula groups were selected randomly for semi-structured interview. The entire process of interview has been audio recorded and the transcript of the same was developed.

(iii) Conducting test and interview

The diagnostic test was conducted in groups where as (whereas) interviews were conducted individually. During interview, NCERT text books of class IX to XII and other reference books have also been provided for scaffolding. Hints have also been given on pictorial representation, numerical calculation, unit and dimension as a part of scaffolding technique to get the best reflection of students on the schedule concepts. The interview was structured around why a respondent gave a particular answer to a test item and the follow up question. The written diagnostic test answer scripts along with the transcript of the interview have been studied in detail to arrive at some conclusion.

Analysis and Discussion

The responses, both in written and oral forms have been analysed question wise below. The investigators attempted to find the genesis of alternative conceptions which may be due to curricula, text books, pedagogy etc.

1. ***Why colour of vein is blue?*** Majority of the pre-service student teachers (93.0%) of all three curricula were not aware of the scientific reason for blue colour of vein. They expressed that the blue colour of the veins is due to flow of de-oxygenated blood through them. However, about one-third (31.25%) student teachers of M.Sc.Ed. curriculum mentioned that some kind of optical phenomenon is involved but failed to express it scientifically/correctly. During interview, most of them were found to be ignorant about visible spectrum of light, primary colours and primary pigments which usually give colours to human skin and also to flora and fauna. In interview, it was also noticed that student teachers are not clear whether the red colour of the blood is due to haemoglobin or due to iron. Surprisingly, majority of the practising teachers (78.6%) demonstrated insecure knowledge about the reason for blue colour of vein like student teachers. However, about one-fifth of the practising teachers (21.4%) were aware of the fact that human skin act as a filter to provide blue colour to veins but are not clear about exact optical phenomena. In interview, when asked to explain/illustrate the exact phenomena, most of the pre-service teachers expressed their inability to answer in terms of optical phenomena. None of the practising teachers knew that veins appear blue because the subcutaneous fat absorbs low-frequency light; permitting only the highly energetic blue wavelengths to penetrate through to the dark vein and reflect back to the viewer. The colour of blood vessels is determined by the following factors: the scattering and

absorption characteristics of skin at different wavelengths, the oxygenation state of blood, which affects its absorption properties, the diameter and the depth of the vessels, and the visual perception process.

During the process of interview, when student teachers were asked, "Have you ever seen your own blood and whether that blood comes from your arteries or veins?" Even those student teachers who have donated blood recalled that the collected blood looks red but not blue. In order to find the genesis of their constructed knowledge on blue vein, many guided questions were asked during interview. The investigators discovered that many student teachers have possessed this misconception since their school days. In the long run, the investigators concluded that the genesis for the above mentioned insecure knowledge about colour of vein prevailing in the mind of student teachers and practising teachers is due to colour used for blood vessels in text books (figure 1). Most of the books use blue colour for veins. This has creped into the mind of not only student teachers but all most all students of different discipline. Hence, here a challenging situation for constructivist pedagogy has been confronted. It reminds us the saying of Jonathan Osborne (2011) – "*it is more important to know what is wrong rather than knowing what is right"*. Hence, it is more important to emphasize the correct fact that human blood is never blue. During interview, it was convinced to the student teachers that blue colour of the veins is due to wavelength phenomena. Mainly two physical reasons emerge for blue colour of the vein. The first is the way light interacts with blood (how it is absorbed) and second, is the way light interacts with the skin (how it is reflected). Blood absorbs light of all wavelengths but less of red part of spectrum. Hence, it looks red. On the other hand blue light does not penetrate skin very well. Human veins are 0.5 mm deep from the surface of the skin. At such distance predominantly blue colour is reflected more and veins appear blue, despite not actually being blue. However, further analysis of diagrams in textbooks is highly indispensible to check the propagation of misconceptions related to colour phenomena.

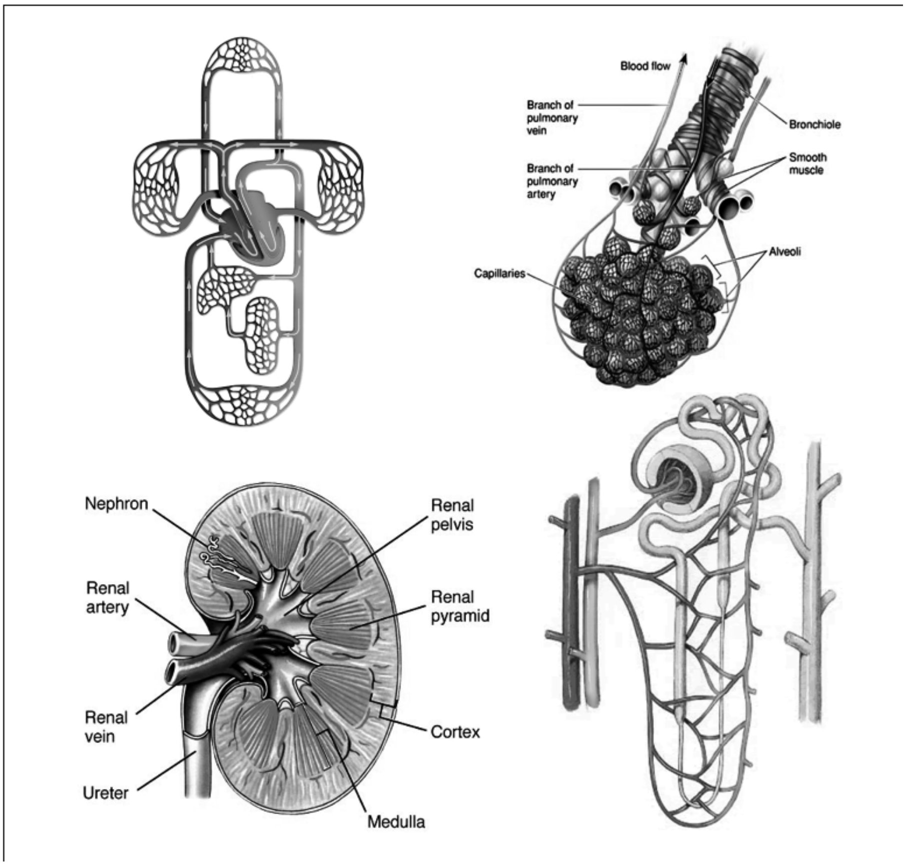

Figure 1. Colour of blood vessels as shown in text books.

Veins blue and arteries red (Darker and lighter respectively in this black and white figure)

2. ***A football player is found to have a resting cardiac output 5 litres per minute and a heart rate of 50 beats per minute, What is his/her stroke volume*****:** Cardiac out put (COP) is the total work done by heart in one minute. COP is calculated by multiplying heart rate (HR) with stroke volume (SV). Hence, SV = COP/HR. This simple mathematical calculation was not known to three-fifth of the student teachers of the across curriculum (65.1%) and majority of the old curriculum (94.1%). Post-graduate trainee teachers (75.0%) could solve the numerical correctly because of their experience and integrated

curriculum. Among undergraduate pre-service trainee teachers, about one-third (34.8%) of across curriculum could solve correctly while none from the traditional curriculum. This clearly reveals that the new curriculum has been beneficial in developing the skill of numerical calculation. Surprisingly, only one-third of the practising teachers (32.3%) gave correct answer while remaining two-third demonstrated weak mathematical analysis. Many student teachers of old traditional curriculum used an inverse formula and ended in wrong answers. When asked in the interview, they admitted that they have forgotten the formula used for numerical calculation and had no conceptual clarity at the time of classroom discussion. Moreover, they confessed because they are not aware of dimensional analysis, otherwise they could have rectified their formula. The present finding clearly demonstrates that student teachers do not have skills to retrieve the mathematical relations for biological processes. Studies on interdisciplinary approach to teaching concepts concerning diversity of life and life processes by Mak et al. (1999), dihybrid and multifactorial crosses by Wegmann (2001) and swimming of planktons by Clay et al. (2008) has concluded that application of standard mathematical formulae can demonstrate predictable events with clarity and accuracy.

It is imperative to note here that mathematics is an essential tool in biology and importance of across curriculum is an indispensible part of higher education in general and teacher education in particular. Moreover, topics of mathematics like statistical analysis, matrices, formulae, calculus etc which are frequently used in biological analysis should be incorporated in biology curriculum. While using formulae for numerical calculations, usually students do not pay much attention towards unit and dimensions. So both physics and mathematics concepts should be equally blended in biology teaching wherever necessary.

3. ***If a person's blood pressure is reported as "142 and 95", what are the diastolic, systolic and pulse pressure?*** In response to mathematical figures pertaining to measurement of blood pressure, more than fourth-fifth student teachers (86.0%) of old traditional curriculum gave incorrect responses in comparison to a little less than three-fifth of the student teachers of across curriculum (58.8%) and post-graduate life science curriculum (56.25%). About one-eighth student teachers (11.76%) of across curriculum gave correct answer that 142 mmHg is systolic pressure, 95 mmHg is diastolic pressure and systolic pressure minus diastolic pressure = pulse pressure i.e. 47 mmHg. None of the student teachers of old traditional and post-graduate curricula gave completely correct answers. Many of the student teachers were not aware of the unit of blood pressure. Among practising teachers, only two-third (66.0%) were aware of the units of blood pressure. Surprisingly, about one-third of the student teachers (29.4%) of across curriculum demonstrated poor understanding of systolic and diastolic pressure. In interview, when asked, *what is blood pressure*? Some of them replied that "*it is contraction of ventricle*". They were not aware of the fact that blood pressure is the pressure of blood with which it strikes the wall of blood vessels during ventricular systole and ventricular diastole (pressure = force per area). In response to another interview question, *what is normal blood pressure*? Some of the student teachers mentioned that normal blood pressure is 80/120 without mentioning what is 80 and what is 120 and what is the unit of blood pressure. Many of the student teachers of post-graduate life-science curriculum affirmed that systolic pressure is higher than diastolic pressure i.e. 142 mmHg is systolic pressure and 95 mmHg is diastolic pressure but exhibited poor knowledge about pulse pressure. The responses in the interview indicated that majority of the student teachers lack basic understanding of manometer, which is a pressure measuring device usually calibrated with atmospheric pressure in the unit of mmHg. However, some student teachers of across curriculum (6.0%) and post-graduate life-science curriculum (5.0%) have some idea about it though not fully. In interview, student teachers and practising teachers when asked to convert numerically 142 and 95 mmHg into bar or Pascal's using the mathematical formula, $P = h\rho g$, where parameters carry their usual meaning, failed to do so. The present study showed that mathematical formulae have become a forgotten tool in biology curriculum. The authors felt that it is necessary to integrate physics and mathematics in biology for better understanding of life processes and other modern areas of biology. Hasting and Palmer (2003) in their study mentioned that it will be difficult for students of today to solve the biological problems of tomorrow if they have not been provided with a basic biophysical and biometrical foundation. When asked in interview, *what is the unit of blood pressure*? Very few of the student teachers of across curriculum (11.76%) could express the units as mmHg but majority were not aware of the fact that pressure is also measured in Newton's per square meter (often called Pascal) or in pounds per square inch. Pressure is also often measured in millimetres of mercury (mmHg), a unit that originated from old-fashioned mercury barometers. The correct formula of pressure to be used here is $P = h\rho g$, where 'h' is the height of mercury column (in mm of Hg) of sphygmomanometer tube, 'ρ' is the density of blood (1060 kg/m^3) and 'g' is acceleration due to gravity. By changing the value of 'h' in the range of 80 to 140 mm of Hg, students were asked to calculate pressure using above mentioned formula during interview. A very similar study on calculation of glomerular filtration rate (GFR) and net filtration rate (NFR) has been conducted by Ortiz (2006)

where students were made to realize that human excretory system also provides oppurtunities for for mathematical applications.

4. ***Schematically represent in correct sequence, which heart chamber, heart valves, and blood vessels would a drop of blood encounter as it flows from the right atrium to the aorta***: Schematic representation is an important tool for sequential presentation of a process/phenomenon without content not only in biology but in all areas of science (figure 2). In the present study, when student teachers were asked to represent schematically the circulation of blood in human body, about seven-tenth of student teachers of old traditional curriculum (69.76%) and post-graduate life-science curriculum (68.75%) showed poor understanding in comparison to student teachers of across curriculum (35.29%). However, about one-half of the student teachers of across curriculum (52.94%) and only few student teachers of old curriculum (4.65%) and post-graduate life-science (12.5%) curricula were partially correct in making the schematic representation of blood flow. Surprisingly, many student teachers of old traditional as well as of post-graduate curricula made pictorial presentation of blood flow in heart only (figure 4).

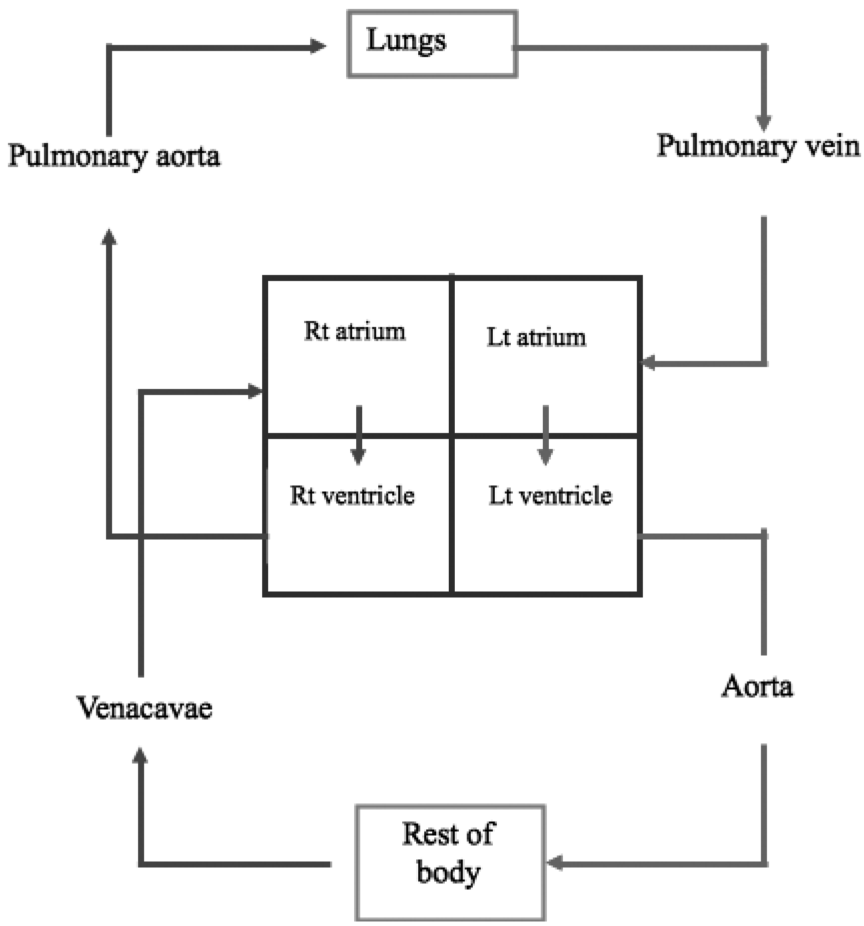

Figure 2. Schematic representation of circulation of blood through heart.

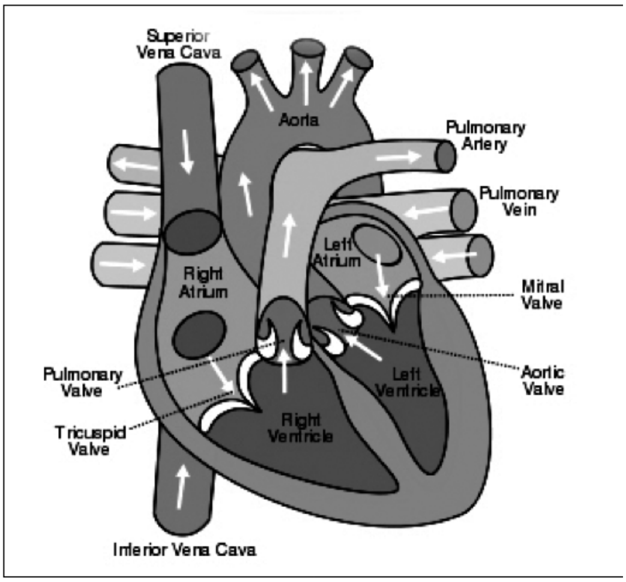

Figure 3. Pictorial presentation of circulation of blood through heart.

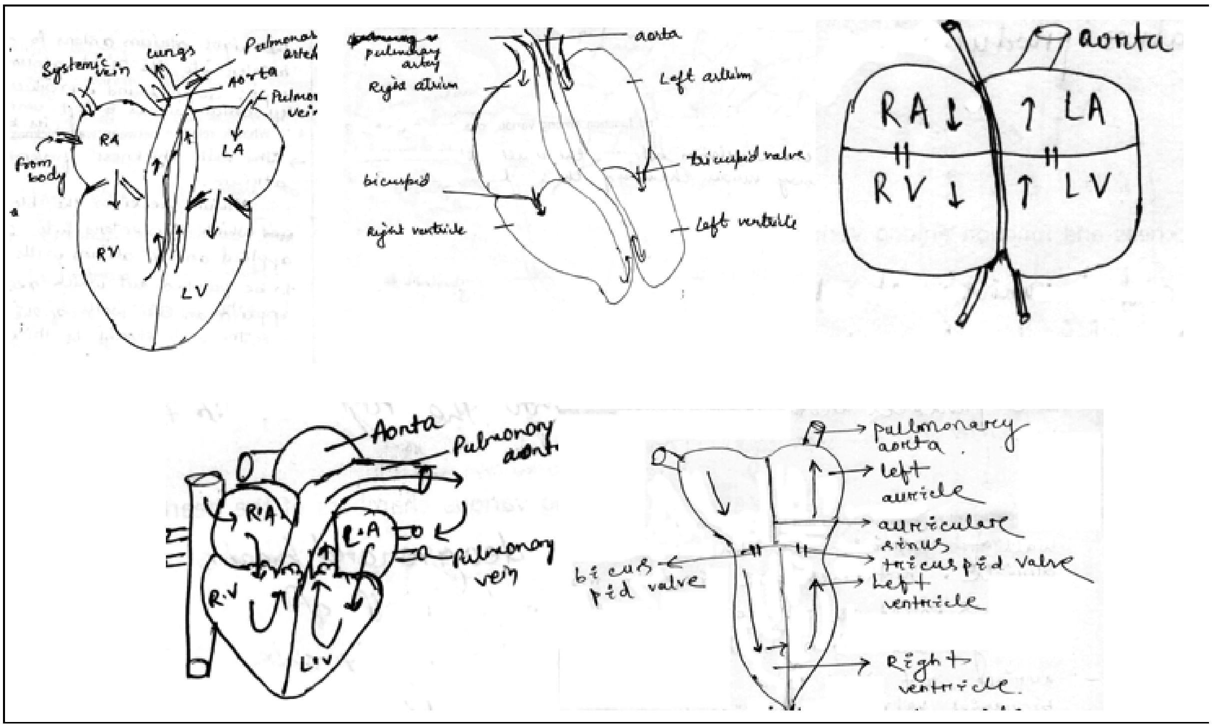

Figure 4. Student teacher's schematic representation of circulation of blood through heart.

The results of present study clearly reflected that student teachers are ignorant about the differences between schematic and pictorial presentation (figure 2 and 3). In interview, when they were asked about schematic representation, they mentioned that both schematic and pictorial presentations are same and are synonyms. We have presented it as it is given in our text books. This indicates that, student teachers are dependant on text book diagrams which are mostly pictorial presentations. However, all most all practising teachers made correct schematic representation of blood flow. The misconception prevailing in the mind of student teachers may be due to the fact that during their classroom interaction, they have not understood the importance of schematic representation in developing conceptual clarity. During guided interview, schematic representation was discussed briefly and student teachers were helped to plot blood circulation through heart schematically keeping the pictorial presentation in front which they have plotted. The investigators could observe high confidence level of student teachers from their facial expression. When asked, they expressed that the schematic representation was a better technique to understand a process. The investigators strongly support the inclusion of schematic representation of complicated processes/phenomena in the text books after pictorial presentation for better conceptual clarity. However, this can be further supported by research in future as it seems not much study has been carried out in this area.

Conclusion

The findings of the above study has revealed following important aspects relating to biology teaching and biology curriculum.

1. Inappropriate colour of the diagrams usually given in the text books and other reference books is the main reason for alternative conceptions of biology student-teachers/practicing teachers related to colour of subcutaneous veins.
2. Lack of basic skills to apply proper mathematical formula for a biophysical process and its accurate numerical calculation is the genesis of misconceptions pertaining to pressure related problems of bioscience.
3. Interdisciplinary approach to teacher training curriculum was found beneficial to strengthen the conceptual clarity of undergraduate pre-service trainee bio-teachers.
4. Schematic representation of veins over traditional diagrams was found more suitable for pre-service trainee bio-teachers to present and retain the sequential procedure of life processes such as blood circulation.

The examples provided here are meant to serve as a spring board from which practising teachers may go forward and expand upon. Interdisciplinary approach enhances critical thinking skills and scientific literacy. A little creativity can go a long way, and the pay-off will be a boon of well-prepared biologists in the years to come.

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Undergraduate Students' Understanding About Representations in Chemistry

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In previous research, students showed poor representational competence in a diagram translation task in the domain of organic chemistry. This study documents findings from interviews and think aloud protocols of 6 undergraduate participants who had taken an undergraduate organic chemistry class. The participants had forgotten some of the conventions of molecular representations that had been used extensively in the class and had incomplete or inaccurate knowledge about the importance of the positions of molecular subsitutents in three-dimensions. One might expect that providing a concrete model of a molecule would aid students in thinking about the three-dimensional structure of molecules. However, when models were made available, the majority of students did not use them spontaneously. We found that a procedure of asking participants to match the concrete models to their solution helped students to understand the critical three dimensional relations, including the distinction between isomers and conformations

Introduction

Stereochemistry is a branch of chemistry that involves the study of the relative spatial arrangement of atoms within molecules. Molecules having same formula with atoms bonded together in the same functional groups, but having different three-dimensional structural arrangements are called structural isomers and they have different chemical properties. When all 4 covalent bonds of a carbon atom are formed with different functional groups, such carbon atoms are called 'chiral' carbons (e.g. Carbon 2 in Figure 1b). Switching any pair of groups around a chiral carbon results in an isomer.

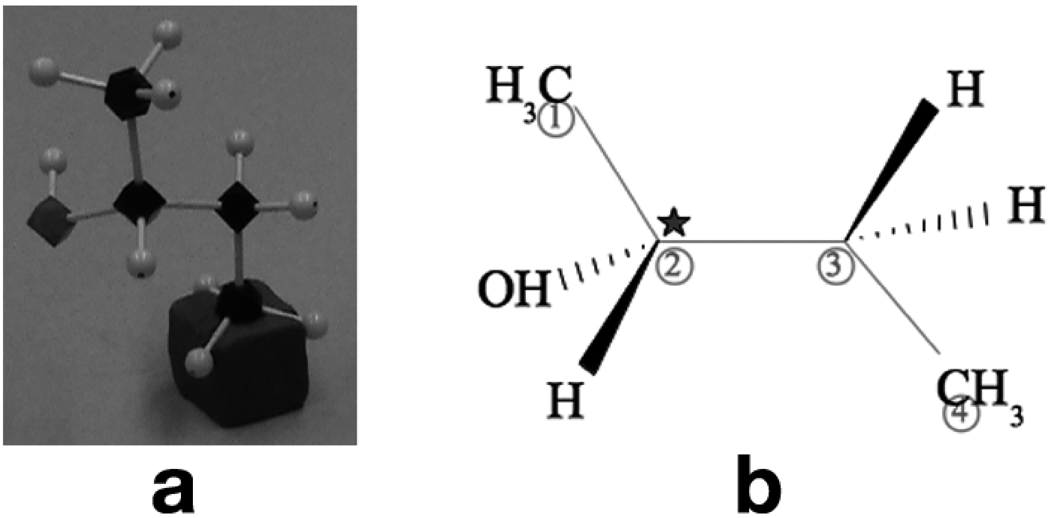

Figure 1. (a): Ball stick model of (S)-2-butanol, (b): The cCarbon backbone is indicated by a red line. It consists of Carbons 1, 2, 3 and 4. Conventionally, carbons atoms at positions 2 and 3 are not shown explicitly. All the bonds in this molecule are single (sigma) bonds. The cCarbon atom at position 2 is a chiral carbon (indicated by an asterisk) because no two groups attached to it are same.

Several kinds of diagrams have been developed to represent molecules in the context of different problem solving situations in chemistry. Among these, dash-wedge structures (DW), Newman projections and Fischer projections are equivalent in terms of the information they represent, but they follow different conventions to represent the three dimensions of a molecular structure in the two dimensions of the printed page, and they depict the molecule from three different perspectives (Figure 2). They are commonly used and hence taught in introductory organic chemistry courses at the undergraduate level. Chemists are often required to translate between one kind of diagram and another and as a result, students are also required to solve diagram translation problems in typical examination problems. Translating between diagrams involve rotation of the entire molecule (holistic rotation) since the molecules are depicted from different perspectives, translation between different diagrammatic conventions, and may also involve rotations around a sigma bond (within a molecule). Thus diagram translation is a difficult task. Ability to perform this task is a good indicator of students' understanding of the three dimensional structure of organic molecules as well as the conventions of diagrams used in the discipline, and it prepares them for further problem solving.

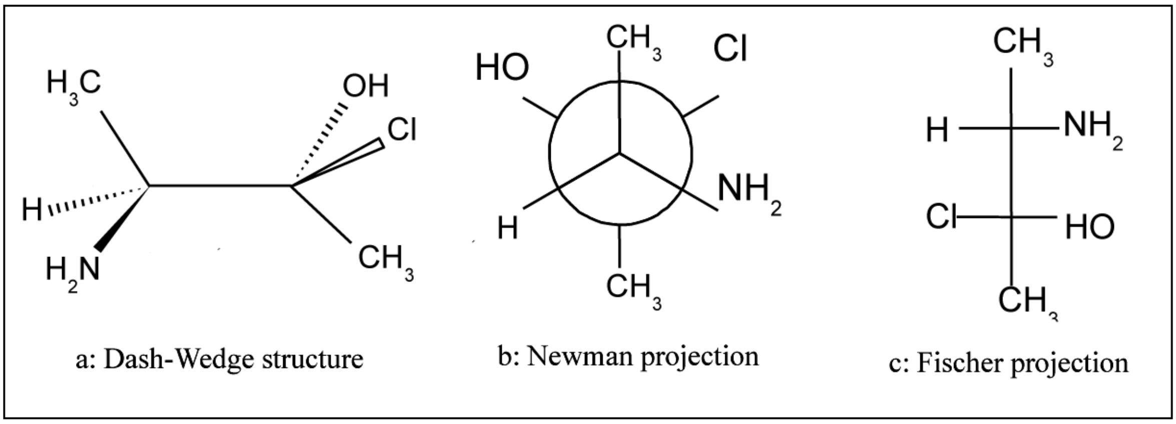

Figure 2. Three kinds of diagrams of trial molecule used for the interview

Previous research showed that students have poor representational competence[1] and their performance on diagram translation tasks is poor (Kozma and Russel, 2007; Stull et al, in press). One might expect that providing a concrete model of a molecule (Figure 1a) with a flexible sigma bond may help in a diagram translation task because the spatial processes such as holistic and sigma bond rotation can be externalised on the model and the students only have to translate between the conventions internally. However, when models were made available to students many of them did not use them spontaneously. Those who used the models performed significantly better than those who did not use the model. However, the average accuracy on the representation translation task was only 33% even when participants were encouraged to use models (Stull et. al., in press). Thus it was clear that the majority of students use strategies (mostly faulty) that did not require concrete models and that they were not comfortable with using concrete models.

In this study we investigated what strategies students use to solve diagram translation tasks, what kinds of errors they produce, and their attitudes towards using models. Our goal was to gain insights into ways of enabling students to perform the diagram translation task successfully.

Method

The participants were tested individually. The research design was a combination of an interview and a think-aloud protocol. First, students were shown one of each kind of diagram and a ball-stick concrete model and interviewed about their familiarity with the conventions of each of these representations. The interview structure is given in the following subsection. If students had forgotten any of the critical information (name/conventions) they were reminded of this information after the interview. Then they were given one diagram of each kind and asked to draw the remaining two kinds of diagrams for the same molecule (For example, given diagram: Dash-wedge structure, Target diagrams: Newman projection and Fischer projection). Thus they solved six diagram translation problems (Table 1) and were requested to think aloud while solving these problems. The experimenter asked for clarification whenever they said something that was not clear. Then the participants solved 12 similar problems without thinking aloud. A concrete model of the corresponding model was available to participants while they solved all 18 problems. A demographics questionnaire was then administered. Finally, participants

1 Representation competence in the context of chemistry is ‘a set of skills and practices that allow a person to reflectively use a variety of representations or visualizations, singly and together, to think about, communicate, and act on chemical phenomena in terms of underlying, aperceptual physical entities and processes’ (Kozma & Russell, 2005, p.131).

completed the Vanderberg and Kuse (1978) Mental Rotation Test as a test of spatial ability (20 items administered in two 3 minute blocks).

The diagrams used during the interview and for the translation problems were presented on sheets of paper (size: 8.5" x 11"). The entire procedure (except the mental rotation test) was videotaped with participants' consent.

Sheet	Molecule	Given diagram	Asked to draw
1	2 amino, 2,3 propanol	DW structure	Fischer and Newman projection
2	2 amino, 3 chloride	Newman projection	Fischer projection, DW structure
3	2 amino, 3 butanol	Fischer projection	DW structure, Newman projection

Table 1. Problems for think aloud protocol.

Structure of the Interview

Participants were first interviewed about Dash-Wedge diagrams, then about Newman projections then about Fischer projections and finally about the concrete model of an example molecule. The following is a subset of the questions about the dash-wedge structure asked to all participants:

- Are you familiar with this type of diagram?
- What are they called?
- Do you know how to draw such diagrams? Do you know how to interpret them? How do you extract 3D information from this kind of diagram? What do the solid lines, dashes (hatched wedges) and solid wedges mean?
- Do you know where the carbons are in this diagram? Can you show me the carbon backbone in this diagram?
- Does the order of atoms/ groups attached to the carbon atoms matter? Is it OK to interchange them?

Similar questions were asked for the Newman projection and the Fischer projection of the trial molecule (questions about conventions were changed as appropriate for each diagram type). Students were also asked whether the molecule in the given diagram was the same as the molecule in the earlier diagram to check whether they understood the correspondence between the three kinds of diagrams. Then the participants were shown a ball-and-stick concrete model of the trial molecule and asked the following questions:

- Have you seen such models before?
- Did you use them during any of your chemistry courses? If so, in which course?
- Do you know what these balls and sticks stand for? What do these black balls stand for? And the small white ones? The red ones? The blue ones? And the green ones?
- Is this molecule the same as the last one (shown in a Fisher projection)?

Participants

Six undergraduate students (3 females) from a research university participated in the study. These students had completed at least one course in organic chemistry (four students had completed two courses and two had completed one course), in which they had been introduced to the three types of diagrams used in this study. Their grades on the introductory course were A^- (two students), B (two students), C (one student) and unknown for one student. Their average GPA was 3.07 (SD=0.36), which indicates that these were either average or good students. Three of the students were sophomores (2nd year undergraduate) and three were juniors (3rd year undergraduate) and their average age was: 19.83 years (SD: 0.98). The participants received $20 for their participation.

Results

The results are presented in three parts. In the first part students' understanding about the four kinds of representations gained from the interview is described. In the second part the results regarding accuracy of solutions to all 18 representation translation problems are given and in the third part strategies of solving diagram translation task that surfaced during the think aloud protocol are described.

Students' understanding of representation

Familiarity with diagrams: All six participants were familiar with all three kinds of diagrams and with the concrete models. However, none of them could name the Dash-Wedge structure correctly probably because these diagrams are default diagrams and are not usually named explicitly during instruction. Four participants could name the Newman projection and five participants could name the Fisher projection.

Conventions: Although students were familiar with all three kinds of diagrams and with the molecular models they had difficulty in remembering their conventions. For the dash-wedge structure, although all the participants remembered the conventions for dashes and wedges, only three could remember the convention that solid lines represent bonds that are in the plane of the page. For the Newman projection, five participants remembered that there is a carbon atom at the intersection of the three bonds but only two of them could remember that that the other carbon atom is at the back of the front carbon, either by comparing it with a dash-wedge structure or when the interviewer gave a small hint. One participant did not remember either of these conventions. None of the participants fully remembered the complete convention for Fisher projections. Two participants remembered correctly that the horizontal lines come out of the plane of the page, but one of them thought that all vertical lines are in same plane. The other four participants did not remember the conventions of the Fischer projection. All of the participants could show the carbon backbone in the given diagram except for one participant who could not show the carbon backbone in the Newman projection.

With regard to the concrete models, all participants knew that a black ball represents a carbon atom, a small white ball represents a hydrogen atom and that the sticks were bonds. Most of them had difficulty in remembering the conventions for coloured balls. When participants were given a hint to pay attention to the number of hydrogen atoms attached to each coloured atom they could identify oxygen, chlorine and nitrogen.

All participants were helped to remember the conventions using the model before the beginning of the problem solving task.

Positions of groups attached to the chiral carbon: As discussed in the introduction, the relative positions of the four groups of atoms attached to the chiral carbon are of great importance. However, our participants' knowledge about this aspect of molecules was incomplete or inaccurate. Three participants in the case of the dash-wedge structure and 2 participants in the case of the Newman projection correctly responded that if the groups on different bonds were switched, it would not be the same molecule. One participant responded that you can switch the groups, but cannot change the position of Hydrogen, since it has lowest priority. The remaining two participants thought that switching the groups would not make any difference. One of them justified their answer by saying that it would be the same compound, even if the groups changed their positions, because the name of the compound would remain the same. Most of the participants were concerned about the energy levels of different conformations, but seemed not to not realise that switching the substituents is different from rotating them.

These responses indicate that the participants did not have clear understanding of the difference between isomers and conformers. This is likely because they did not have a basic understanding of the geometry of molecules, or about the consequences of rotation and switching (they seemed to think that switching groups of atoms (substituents) is same as rotating substituents around the bond.

Correspondence between representations: Three participants responded that the molecule represented in the dash-wedge structure and the Newman projection were the same, but only one presented a convincing strategy for showing their correspondence. She held the sheet with the Newman projection vertical (perpendicular to the one with the dash-wedge structure), drew an eye on one side of the dash-wedge structure to indicate that she is looking at the dash-wedge structure from the side and showed the correspondence between the molecular substituents (i.e., atomic groups); the other two participants only matched the substituents that were attached to the chiral carbons, and did not pay attention to their positions in 3D space.

Participants were not asked about the equivalence of molecules in Newman and Fischer diagrams, but all of the participants were asked to match the model with each of the three diagrams. Three participants could align the model with the dash-wedge structure, four participants could align it with the Newman projections and four could match it with the Fischer projections (sometimes following a small hint). All of the participants took a long time to align the models and see the equivalence. Participants who could not align the model with the diagram were helped in establishing the correspondence.

Thus establishing the correspondence between different representations was not easy for students. Here students have to consider two aspects: correct perspective and correct configuration (staggered & eclipsed[2]). Accuracy of solutions

Out of the first six problems solved while giving a think-aloud protocol, on average 3.5 were correct (SD=1.64). Out of the twelve problems that students solved on their own, on average 7.0 (SD=5.22) were correct. Thus taking all 18 problems together, 58% problems were solved correctly. Out of the 42% incorrect solutions, for 34% of the problems the participants had drawn isomers of the given molecules, for 3% of the solutions, the template of the dash-wedge structure was incorrect and for 5% of problems the participants attached incorrect groups to the chiral carbons (the first two errors were made together in two problems). Thus although most of the students drew diagrams that showed the correct attachment of substituents they did not attach the substituents at the correct position in three dimensional space and ended up drawing an isomer of the correct diagram .

Strategies for solving diagram translation task

For the first six problems, 24 out of 36 times, participants completed the template of the target diagram before filling in the substituents. In the rest of the solutions they simultaneously drew parts of the template and assigned the groups.

The strategies documented by the students during the think aloud protocols can be divided into 5 different types: 1. random/ guessing, 2. rules and/or algorithms (sequence or steps) 3. mental visualization 4. diagrammatic strategies and 5.using concrete models. This scheme of classification is derived from the scheme of Stieff & Raje (2010). Examples of each of these strategies along with transcripts are provided below. The number of times each kind of strategy was reported by the students is given in Table 2 and Some participants used more than one strategy to solve a problem, hence the number of strategies documented (42) does not add up to the total number of problems solved by all participants (6*6=36)

Problem	Random/ guessing	Rules and/or algorithms	Mental visualization	Using model	Diagrammatic
Total	4	8	7	22	1

Table2. Number of times each strategy was recorded by students

Random assignment/ guessing

Ps2, 5: "Tic-tac-toe. I just randomly picked that. I could have switched these two" (DW-F)

Ps1: "I learned how to do it as opposed to visualize in my head (by) practicing a lot of problems. I just know that that was a right answer."

Rule and/or algorithms: Students follow certain rules

Ps1: Diagonal groups in Newman diagrams are placed on the same side of Fischer diagrams. (N-F)

Ps1: Opposite groups (in the Newman projection) are on same type of line (in dash-wedge structure). (N-DW)

Ps1: Tried to determine R & S[3] on both sides of DW. (N-DW)

Diagrammatic: Ps4 drew a different type of diagram (a Kekule diagram) as an intermediate diagram while translating from a dash-wedge structure to a Newman projection.

Mental visualization (without using model):

Ps1: “These two (bottom-left and top-right in Newman diagram) are supposed to be on the same plane. And these two (bottom-right and top-left in Newman) are in the same plane” (DW-N)

2 Staggered conformation: substituents on adjacent atoms are at the maximum distance. Eclipsed conformation: two substituents on adjacent atoms are in closest proximity

3 The *R / S* system for denoting enantiomers: substituents at each chiral atom are each assigned a *priority* based on atomic number. If the center is oriented so that the lowest-priority of the four is pointed away from a viewer and if the priority of the remaining three substituents decreases in clockwise direction, it is labeled *R* (for *Rectus*, Latin for right), if it decreases in counter-clockwise direction, it is *S* (for *Sinister*, Latin for left)

> Ps3: "(I'm) rotating it in my head. If I look at it from here (drew eye on left of DW) and showed corresponding atoms. Rotating in this way (drew arrow). If you look at it like this and you flat it out..." (DW-N)

Using model: All of the participants were asked to align the concrete models with all three types of diagrams during the interview and if they were unable to do so, they were helped to match the models and see the correspondence. Participants 1 & 2 were reluctant to use the model and the interviewer could not convince them that using models might be useful.

Participants 3, 5, and 6 did not use the model initially, but they were asked to match the concrete model to check their solution for the first problem. These participants realized their mistakes in this process and drew corrected solutions. The same procedure was repeated for participants 5 and 6 for another solution. Participant 4 figured out how to use models on her own. As a result, Participants 3, 4, 5 and 6 used models for solving the rest of the problems (22 out of 36 problems as seen in Table 2). They struggled aligning the models with the given diagrams, including trying multiple rotations, wanting to switch the substituents on the models, and trying to make the bonds more like right angles or in the exact same plane. They made mistakes while putting the groups on templates even when the model was correctly aligned to the target template. However, after a couple of trials they learned and then became extremely efficient in using models and solving diagram translation problems. On average, out of 18 problems, Participants 3-6 solved 14.5 problems correctly as compared to 2.5 problems solved correctly by Participants 1&2.

Thus, once participants understood how to use the models, using models became their most common strategy. Before that, or for students who did not learn to use the models, using rules or algorithms was the most common strategy.

Conclusions

The results indicate that students who have taken an introductory organic chemistry class were familiar with three types of diagrams, and a type of concrete model that are used extensively in their classes. They understand which substituents are attached to which chiral carbon atoms but draw them in incorrect positions. There are two possible reasons for this result. First, students might have forgotten the conventions for representing the three dimensional structure in a two-dimensional diagram (this was particularly true for Fischer projections). But even when students were reminded of the conventions during the interview, for 34% of the problems, students drew diagrams of structural isomers of a given molecule rather than one of its conformations. This meant students did not understand the difference between conformations and isomers of a molecule. Structural isomers are a result of switching the atomic groups (substituents) around a chiral carbon (e.g., reflection) and conformations are the result of rotation of atomic groups around the chiral carbon. Students probably do not distinguish between reflection and rotation and this might be key to their inability to see the differences. Given that students were not able to understand and perform spatial transformations critical in the diagram translation task, they used either rules or error-prone algorithmic strategies to solve diagram translation tasks or assigned the groups randomly. Thus the spatial component, which is a critical component of stereochemistry, was found to be missing in students' understanding.

The subtle differences caused by similar spatial operations such as rotation and reflection are difficult to understand if one carries out the operations mentally because of limited short term memory. Concrete models are an appropriate tool to make this distinction clear. However, although students are familiar with models, they do not seem to understand the correspondence between different kinds of diagrams and concrete models. More importantly they do not understand that they can externalise the spatial operations onto models to translate between the diagrams. Thus, it might be important to instruct them on how to relate the concrete models to diagrams, through actions.

Our findings helped us in designing further instructional interventions in two ways. Since most of the participants did not remember the conventions fully, we provided an instruction sheet which provided the conventions for each kind of diagram and for concrete models at the beginning of further intervention studies involving diagram translation tasks. This ensured that students' impairments in performance were not due to failure to remember the conventions correctly.

Secondly, the procedure of asking participants to match the concrete models to their solution seemed to help students to understand two things: (1) that their solution was incorrect and (2) the distinction between isomers and conformations. We designed a short intervention based on this finding which was found to be highly successful in a pretest-posttest comparison (Padalkar & Hegarty, 2012).

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Mathematical Creativity as the Jumpstart to Reform of Teaching Mathematics

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Teaching-Research (NYC model) is the methodology practiced in mathematics classrooms of community colleges of the Bronx[1]. TR-NYC methodology of teaching research is the investigation of learning simultaneously with teaching for the purpose of improvement of the learning in the immediate classes of practice and beyond. It operates via the cycle is shown below. Teaching-Research Experiments (TREs) have been conducted in classes of Arithmetic and Algebra since 2006, following success in Calculus classes (NSF-ROLE#0126141), and success in Arithmetic and Algebra began in 2010.

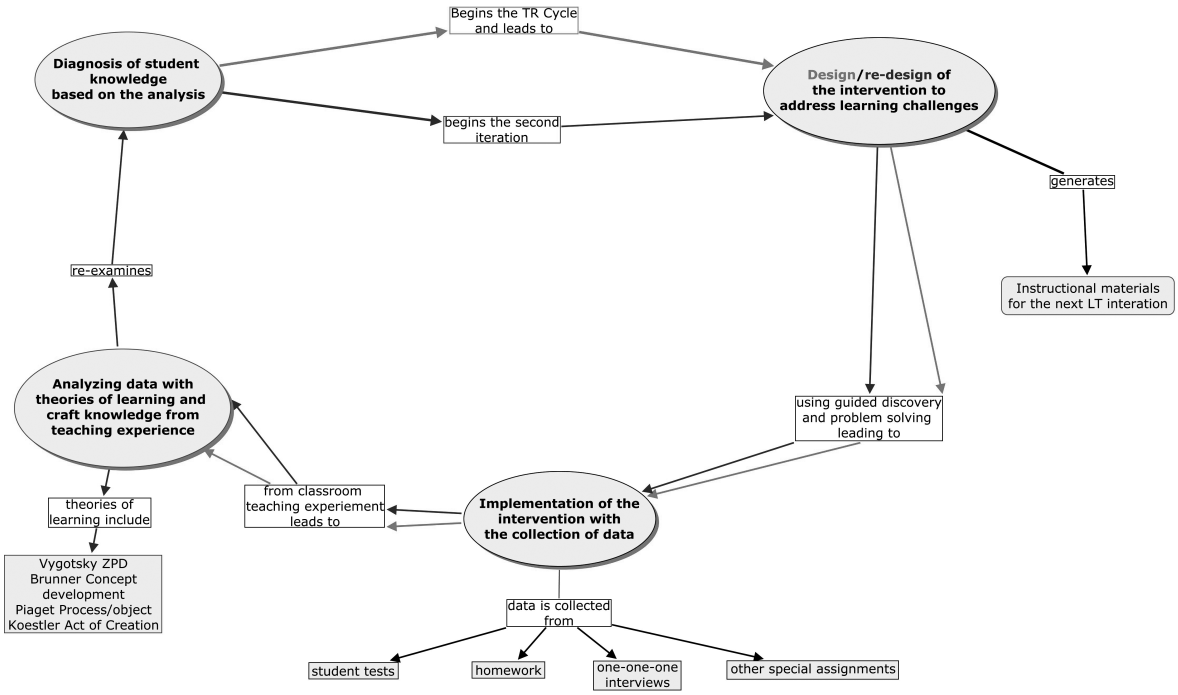


Figure 1. Teaching- Research TR-NYC Model

Student learning is facilitated through a Creative Learning Environment (CLE) comprised of simultaneous attention to

- Well-scaffolded cognitive challenge
- Elimination of affective inhibitions
- Support for self-regulated learning practices

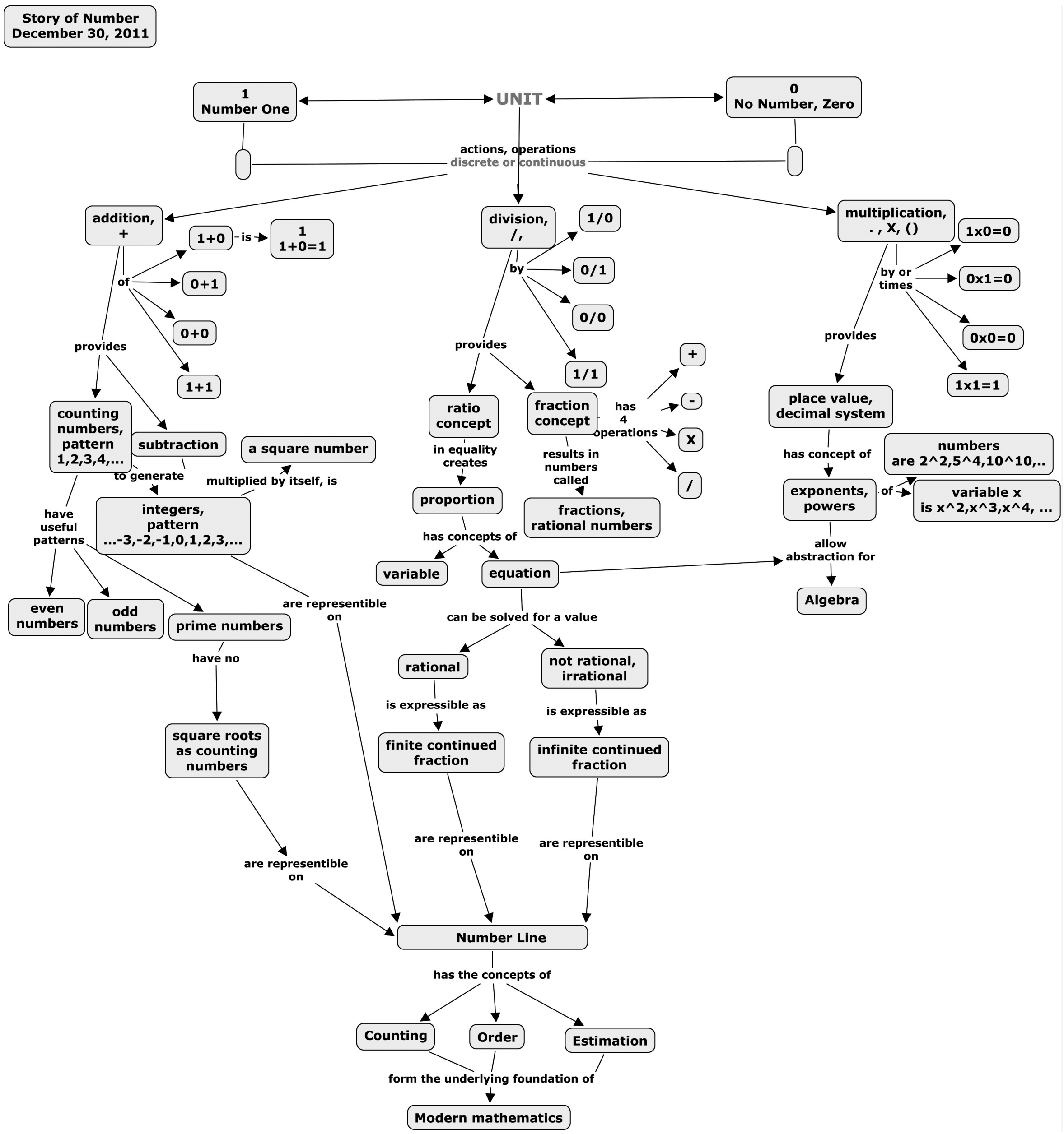
How is the cyclical Teaching-Research TR-NYC model able to accomplish the transition from what is required to what is made possible over the given span?

When we look upon the TR cycle and its different components, in general, we imagine an object to be produced by our work along it, viz., student mathematical knowledge. However, when we analyze what is happening with the knowledge of the teacher-researcher working through the cycle repeatedly in an effort to improve student knowledge, we also observe significant developmental changes in that knowledge. By the continuous process of refinement of instruction with mathematical concepts, the teacher-researcher's understanding of the taught

1 Partial funding for this initiative is made possible through CUNY CCCIRG 7, Problem-Solving, A Jumpstart to Remedial Reform

concept dramatically increases by clarifying its place within the relevant mathematical schema. As a result, the global view of the teacher-researcher upon the taught subject becomes more detailed and better connected – in short, the teacher-researcher begins investigation of the mathematical concepts in question well-beyond the usual curricular form, based on student questions that arise and the difficulties students demonstrate in learning. The teacher-researcher can consequently guide students better. In other words, TR cycle dynamically facilitates creativity, because it is based on two different conceptual frames of teaching and research, which result in professional development of the teacher together with the improvement of practice. The impact of this on student learning is significant.

The questions that are addressed in the actual process of the TRE are:



What does it mean to tackle mathematical creativity for students disenchanted and disenfranchised from learning of mathematics? Why is understanding an important element of freeing of expression of mathematical creativity? What is the profundity expressed by students of mathematics in our classes? How do conceptual structures emerge in mathematics teaching research? Why is teaching-research in vivo? etc.Figure 2. Story of Number

The concept map below is an example of the resulting creativity of the teacher-researcher prompted by students' questioning the continuity of the realnumber line, thus facilitation of student creativity is grounded in the teacher-researcher's creativity.

Theoretical Framework

Our theoretical lens that allows investigation of creativity is guided by A. Koestler (*The Act of Creation*, 1964). In particular, for a teacher-researcher, not only is the theoretical lens of significance, but furthermore, that theoretical lens provides the direction for the development of the classroom instructional materials and classroom discourse. Within the context of application of Koestler, the first such tool is the Triptych[2]. The triptych consists of "three panels..indicating three domains of creativity which shade into each other without sharp boundaries: Humor, Discovery and Art….Each horizontal line across the triptych stands for a pattern of creative activity which is represented on all three panels; for instance:

Comic comparison ←→ objective analogy ←→ poetic image

Figure 3. Triptych from Arthur Koestler, *The Act of Creation*

The first is intended to make us laugh; the second to make us understand; the third to make us marvel. The logical pattern of the creative process is the same in all three cases; it consists in the discovery of hidden similarities. But the emotional climate is different in the three panels……..The panels on the diagram meet in curves to indicate there are no clear dividing lines between them." Addressing the emotional/affective mindset of the learner is essential in our work (Barbatis, et. al, 2011) and the triptych is our mechanism integrating affect, cognition and required self-regulatory learning practices. Consider the use of the triptych in an Elementary Statistics class, which was provided a skeletal triptych where the central column of Discovery constituted 8

2 Koestler's Triptych is appended at the end of this article.

central concepts of the course. Two of these rows were completed. The first row was completed in interactive discussion with students. The triptych is shown below:

Trailblazer ←→ Outlier ←→ Original/ity

←→ Sampling ←→

←→ Probability ←→

←→ Confidence interval ←→

←→ Law of large numbers ←→

Lurker ←→ Correlation ←→ Causation

Lurking variable

Student thinking is made visible to the instructor through this exercise, and allows the theoretical intention of repeating the teaching-research cycle over student difficulty twice in the semester (Czarnocha and Maj, 2008)). In an Elementary Algebra class, the triptych provided was briefer and here the exercise was for students to generate the central column of concepts they found difficult in the course. 3 rows were provided. Student work was revealing in this context, and is partly shown below:

**beginning of student work

Number ←→ ratio ←→ division

I would like to understand better how to divide polynomials

I do not really have an understanding of what ratio is.

Part-whole ←→ fraction ←→ decimal

I need a lot of help with part and whole numbers, especially to divide them. With fractions, I would like to understand

When do I multiply, divide, subtract and when to find LCM's etc.

Radical Fractions I do not really understand at all

Particularity ←→ abstraction ←→ generality

←→ variable ←→

I do not know what a variabe is.

**end of student work

The bidirectionality of Teaching-Research, TR-NYC model, allows learning from theory to practice and vice versa to be an ongoing process. Mathematical creativity found to be emerging from craft knowledge of the teaching-research team and coordinated with the research base of the profession through Koestler's bisociation of teaching and research begins the process of building theory supported by, emerging from and combining practice.

The process through which learners make "the creative leap of insight" is coined "bisociation" by Koestler. Creativity is important in its own right, however, in the context of the mathematics classroom in which learners may have had several earlier exposure to the concepts in question, without mastery experiences, there is an additional need to transform habit of "not being good at math" into originality, i.e., one of enjoyment and mastery of the mathematical concepts in question. Thus, bisociation defined[3] as "the creative leap which connects previously unconnected frames of reference and makes us experience reality on several planes at once". Facilitation of bisociation through the triptichs is an example of integration of theory and practice. Given that bisociation can transform habit to originality the question is, how instruction can prepare the environment through which learners make this transformation?

3 Note the similarity of this definition with the quote of Einstein used on some of our syllabi: What precisely is thinking? When at the reception of sense impressions, a memory picture emerges, this is not yet thinking, and when such pictures form series, each member of which calls for another, this too is not yet thinking. When however, a certain picture turns up in many of such series then – precisely through such a return – it becomes an ordering element for such series, in that it connects series, which in themselves are unconnected, such an element becomes an instrument, a concept. A. Einstein, Autobiographical Notes, p.7).

Conclusion

Creativity is the tool for the teaching-research team. Creativity is the engine of discovery both in the design of learning materials and in the self-motivated student partnership. The concept map above is an example of the creativity of the teacher who has transformed into a teacher-researcher and integrated three conceptual frames of knowledge: of mathematics, of her craft knowledge of teaching, and a theory of development of elementary mathematical concepts. The utmost simplicity of the design which integrates three different Learning Trajectories of addition, multiplication and division, allows both the teacher and the student to be guided, the latter in learning, the first one – in teaching. It is precisely that instructional creativity of the teacher-researcher that has to become the foundation, which jumpstarts the real reform in mathematics education. The triptych allows student thinking to make itself visible to the instructor, the concept map allows the instructor to extend the ZPD from where it has made itself transparent, the teaching-research cycle facilitates the process.

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A Network Model of the Mathematical Concept of Area

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The concept of area is important in mathematics learning, as it is the entry point to the deep connection between multiplicative and geometric structures, and requires integrating numerical and geometric understanding. The notion of area as an array of units is central to understanding the area concept. Previous works show that array representations can enhance: 1) learning the spatial structuring of units in the area concept, and 2) the understanding of the two-dimensional nature of the multiplicative process. Extending this dual (spatial and numerical) role played by arrays, we reformulate the area concept as a network, requiring a coagulation of spatial and numerical concepts. Starting from this theoretical model, we developed a spiral of physical manipulations, addressing different aspects of the area concept, to explore whether and how students tie together the different individual concepts in the network. Preliminary results show that students implicitly use multiplication concepts while solving an area problem, but the application of the individual concepts to the area concept is implicit, inconsistent and unstable. We argue that these results support our network model of the area concept.

Introduction

The problem of understanding the mathematical concept of area is usually seen as involving coordination between spatial and numerical representations (Sarama & Clements, 2009). At the operational level, many tasks seek to help the student transit from a qualitative (geometrical or spatial) to a quantitative (numerical) way of thinking about spaces, through the process of partitioning a space, and then arraying the unit parts (Battista, 2007). However, while measuring the area of a rectangle, which provides the foundation for the quantification of area, apart from a proper recognition of the unit and its relation to the given measure, one also needs to know the array structuring of units, and understand area as the product of the rectangle's length and breadth. Thus, the array concept forms the basis for both 1) area-measurement, and 2) the role of multiplicative thinking in calculating area.

In a different vein, many studies report the importance of the array concept for learning multiplication itself, and thus developing multiplicative thinking (Loveridge & Mills, 2009; Barmby, Harris, Higgin, & Sugget, 2009). This is wider than multiplication, and involves a broad range of topics, such as understanding the inverse relation between multiplication and division, part-whole relation, fractions, proportions, etc. It is interesting to note in this context that similar to area, some of these concepts involve spatial relations. Multiplicative thinking leads to a multiplicative response to a situation, by identifying or constructing the multiplicand, the multiplier and their simultaneous coordination in that situation (Jacob and Willis, 2003). Loveridge & Mills (2009) elaborate on Sophian (2007) to argue that the (conceptual) structure of multiplicative thinking has a proportional basis, which involves equal-sized parts or groups, while additive thinking has a part-whole structure, with unequal-sized parts. They further state that the concept of a unit plays an important role in the understanding of multiplicative relationships, which usually develops from the context of additive reasoning. According to this view, the need for multiplicative relation is realized when the units of quantification is other than one (i.e. either a composite unit or a fractional unit). Sophian (2007) claims that young children lack the understanding of constant units while doing equal sharing, and tend to divide a continuous quantity into some specific number of pieces, ignoring the size of the pieces (cited in Loveridge & Mills, 2009).

Davydov (1991) points out that multiplication, as an operation, is distinct from addition, and has measurement in practical contexts as its source (cited by Clark & Kamii, 1996). Barmby. et al. (2009) suggests that addition and subtraction could be viewed as unary operations, with each input representing the same quantity, while multiplication needs to be seen as a binary operation with two distinct input quantities. They state that the four important aspects of multiplication are: replication, binary nature of multiplication (as two different quantities), commutativity, and distributivity. They propose that array could be considered as a key representation for multiplication, as it helps in moving from an operational or process view, to a structural view of multiplication. Unlike array representation, equal-grouping and number-line representation encourage unary thinking and repeated addition method respectively, but miss two important aspects of multiplication, namely commutativity and distributivity. For example, when the numbers are swapped in these representations, they look quite different, and the commutative law is not immediately obvious. The array representation encourages students to think about multiplication as a binary operation, with rows and columns presenting the two inputs.

This short review suggests that the array structure can be used to facilitate the understanding of both area-measurement and multiplication, and in turn, that multiplication and array are key components of the area concept. Based on this interconnected relation between area, array and multiplication, we develop a view of the area concept that is different from the one suggested by the standard model of a learning trajectory where the learner moves from a qualitative to quantitative understanding of space. The interactions between the qualitative and quantitative concepts may be complex in this view, but the learner's progress is usually viewed as a linear trajectory. In contrast, we propose a network model of area, and a spiral model of learning this concept, where many different passes through the components of the network leads to an integration of the concepts, and thus a proper understanding of the concept of area.

Area: A Network Model

We view the (initial) area concept as a network concept, requiring the coming together, or coagulation, of four ideas – unit, array, multiplication, and unit of units. The last could be viewed as an array of arrays, and we introduce below a broader concept related to this, which we term extrapolation. Students usually do not have a fully developed understanding of these individual ideas when the area concept is introduced. Also, these concepts could be: partially or implicitly known, partially stable, understood in an intuitive/qualitative fashion, connect to each other in unstable ways, and some of them may not be known. Figure 1 presents a concept map of this network notion of area.

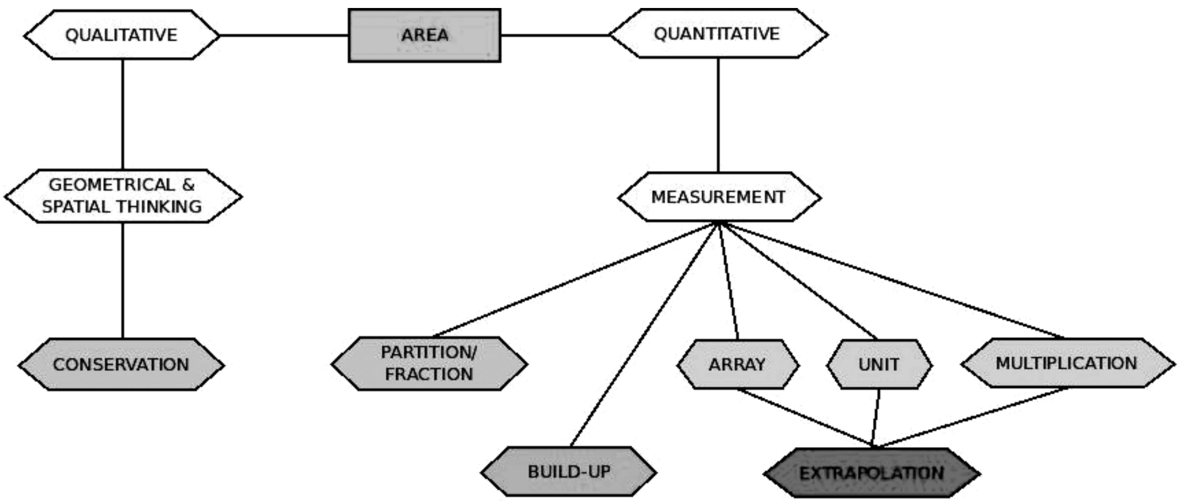

Figure 1. A network representation of the area concept.

The elements (Array, Unit, Multiplication) on the right indicate the standard concepts/operations associated with area. The elements (Conservation, Partition/Fraction) indicate tasks used to facilitate the understanding of area. The element (Extrapolation) indicates a new concept/operation we introduce. The element (Build-Up) indicates a new task we have developed to explore area.

Extrapolation

In relation to the network notion of area, we introduce a new concept/operation –extrapolation, which we consider a key part of understanding the area concept. Extrapolation refers to the use of the multiplication algorithm to calculate the area of rectangular spaces that are very large (or very small, folded etc.), where physical arraying is impossible or difficult. This operation, we believe, is one of the key objectives of learning to calculate area using the multiplication algorithm. Further, the ability to do this operation is an indication that the learner has consolidated her understanding of the connection between area, array and multiplication.

We would like to note here how this view is different from the standard way of testing the area concept, which usually involves calculating the area of complex figures made up of standard shapes, such as an L-shaped figure made of two rectangles. This task is a variant of the partitioning task, requiring the learner to imagine partitioning the given complex figure, and consider it as being made up of some shapes whose areas can be easily calculated, and then applying the multiplication algorithm to each partition (given some values for the sides), and then adding the results.

The extrapolation test, on the other hand, requires the learner to imagine how the area of a large space (such as the floor of a room) could be *measured* using a known shape (such as a square). The multiplication algorithm is then applied twice, first to her known unit, and then to the larger unit measured by it. This operation requires a deeper understanding of the array structure, where any space is seen as an array of units, and any given unit can be used to build up an array. Further, it requires understanding the relation between multiplication and arrays, as the unit is used to measure only the *borders* of the larger space. It also requires a deeper understanding of the relation between multiplication, array, and measurement, where the multiplication operation used to calculate the area of the given unit is extrapolated to a wider space through the use of the given unit as a measurement unit. Ideally, learners who understand the area concept should be able to move quickly to this operation. We believe that the extrapolation operation should be one of the key objectives of learning the area concept, and this operation needs to be supported by tasks designed to teach the area concept.

The present study explores how the above network of related concepts involved in area and multiplicative thinking could be checked, and also built up, through a task series based on physical manipulations.

Intervention Design

Physical manipulation of objects has been suggested as one way of facilitating the understanding of abstract mathematical concepts with spatial elements, such as fractions (Martin & Schwartz, 2005). The authors argue that physical actions can support symbolic learning, as learning of abstractions require reinterpretation, and this is difficult by just thinking. They have proposed four ways in which physical actions could support learning and thinking (Induction, offloading, re-purposing and physically-distributed learning). Physical actions play these supporting roles based on the degree of stability in ideas and environments. This relation is captured by figure 2.

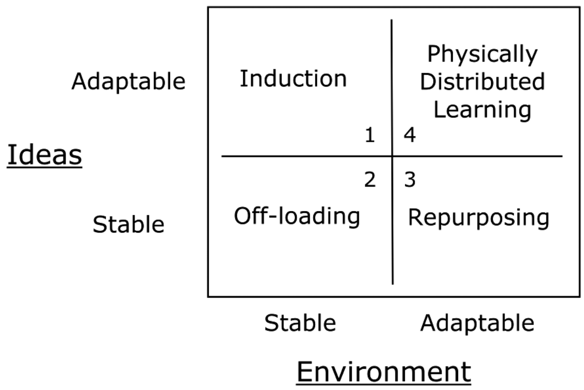

Figure 2. Drawn from Martin & Schwartz (2005)

Based on this conceptualization, the authors show how some physically distributed learning tasks leads to the learning of fraction concepts. This intervention, and the interactionist model of cognition underlying it, has inspired the design of our tasks reported in the next section. However, we consider the authors' way of characterizing the link between concepts and actions adequate only for developing interventions that address the fraction concept. Given our network view of the area concept, we consider this account insufficient as a starting point for designing physical manipulation tasks that facilitate the understanding of the area concept. This is because it is unclear what 'stable' means in relation to a network concept.

As we discussed above, the different concepts involved in the network may be partially known, stable to different degrees, or their interconnections could be unstable. To address this 'patchy knowledge' problem, we believe the physically distributed learning paradigm needs to be extended, to include a series of tasks, which, when done in an interconnected and spiral fashion, seek to bring closer together the ideas involved in the area concept. We outline below a pilot study that investigated such a task series, which we developed and explored with 5th grade participants.

Pilot study

To explore the network notion of the area concept, we developed four tasks, organized in a spiral, and roughly mapped to the four components involved in the area concept: unit, array, multiplication, and unit of units (extrapolation). One objective of this task series was to have a physical and observable process, so that we could keep track of how students progressed through each individual task, as well as the series. The methodology adopted for this study is microgenetic, since we were focusing on the processes involved when students were doing the tasks. Task-based interviews were done either in school or in the research institute. Interviews were video recorded with prior consent from the students and their parents. The video data was used for analysis.

Sample

The participants were grade five students, ten from one school and nine from another school. The tasks used were similar, but not identical, across all the students, as the tasks were progressively modified along the course of the study. The response and approach adopted by the initial students helped in the refinement of the tasks. This paper reports an analysis of eight students, four from each of the two schools, as these students were exposed to the exact identical tasks reported in the next section.

Tasks

1. Qualitative comparison task: This task required students to compare two pairs of rectangular sheets, with a small difference either in length or breadth, and find which sheet was bigger. The aims of this task were: (a) to prime the student with rectangular sheets, and (b) to explore whether the students were sensitive to the two-dimensional nature of area, or whether they only focused on one-dimension, such as length or breadth.

2. Build-up task: This task involved building up a rectangle using a set of squares. The number of squares was carefully chosen, to map to the multiplication table, or not. This task had a set of objectives. One, it sought to understand how students related numbers to rectangles. Two, it explored whether, and how, students used the multiplication table while making an array structure. Three, it sought to prime students about the relation between multiplication and arrays.

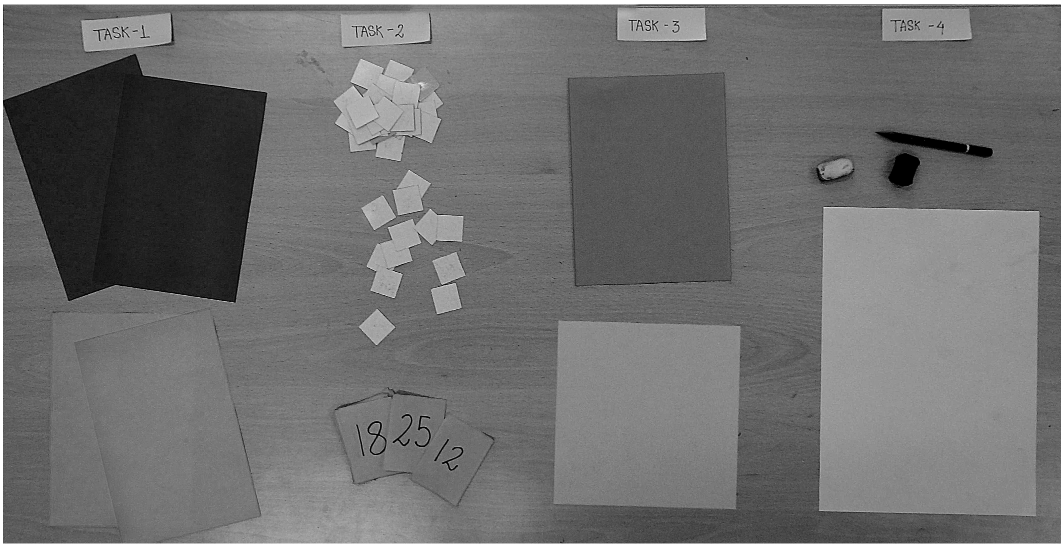

Figure 3. Materials used for the tasks

The task proceeded as follows for each student. The student was first shown small sheets with different numbers written on them. These were held with numbers facing the experimenter, and the student was asked to pick one sheet. Once the number was picked, the student was given that number of unit square cards (1inch×1inch), from a box of such cards. She then had to build-up a rectangle with those many cards. The student first physically arranged the cards to get the rectangle. She was then asked the number of cards in the length and breadth of the resulting rectangle.

This task is the opposite of the standard partition task, and seeks to build up a geometrical figure from a set of parts. The flexibility provided by physical manipulation potentially allowed students to develop rectangular array structures with various dimensions, and thus understand the relationship between the given number, the dimensions of the rectangle, and multiplication. Since the task requires overt action on the part of students, it also allowed us to infer their understanding of the multiplicative relation from their actions.

This task had a second phase, where, after a few trials, students were given a number, and before they physically created the rectangle by arranging the cards, they gave verbal responses about the possible rectangle.

Particularly, whether they could make a rectangle with the given number of cards, and the number of cards that should be used along the length and breadth.

In this second variation, students were shown one of the following multiples or primes (10, 12, 14, 15, 16, 18, 20, 21, 24, 25, 11, 13, 17, 19, 23, 29) in random order, but starting with the simple composite numbers.

The aim of this variation was to prompt them to see how the given number could or could not decompose into factors yielding the array structure, by asking them the number of cards in the length and breadth. This could prime the multiplicative relation between the given number (of cards), and the way its factors correspond to the length and breadth of the rectangle.

3. Quantitative comparison task: This task returns to the comparison operation (thus creating a spiral in the task series), but now the comparison is more complex, and informed by the numerical and spatial manipulations done in the build-up task. The task was to compare a given square sheet (7inch×7inch) with a given rectangular sheet (8inch×6inch) and find which is bigger. Students were prompted with a context, e.g. "I need to cut squares of this shape from the rectangle" to help them comprehend the task. Since the shapes are different, qualitative comparison is difficult (e.g. overlapping). To build on the previous task, the students were given a square card (1inch×1inch) and were asked to use it. After the build-up task, this measuring task allows us to explore the various strategies (e.g. array structuring, complete covering, multiplication, etc.) used by students while measuring the sheets.

The aim of the task was to see whether the previous build-up task (array structuring) helped them in understanding the relation between area and arrays, to the point where they could think of comparison in a numerical fashion. The task also allows seeing whether the students use the multiplicative or addition relation to get the measure of the two areas.

4. *Unit of units (Extrapolation) task*: This task tested whether students could do the extrapolation operation. It represents another spiral in the series, as it creates a version of the build-up task, using the elements from the previous comparison task. The task required using the rectangular sheet of the earlier task, to get an area measure of an A4-sheet, and then using the A4-sheet to get the area of a table. The students were given an A4-sheet, and they were free to use the materials used in the previous task.

This task sought to explore whether students could extrapolate their understanding of area-measurement to bigger rectangles , and use an efficient unit for measuring. This task also creates the need to optimize the number of operations, as it is difficult to measure the table using the small square unit. This means the students have to think of the nested multiplicative relation.

Preliminary Results

We report findings from a detailed analysis of the responses of eight students, four from each school. A few events from earlier interviews (of the remaining students) are also presented.

1. In the qualitative comparison task, there were minute differences either in length or breadth between the sheets in each pair, which one cannot make out by merely looking. Students were shown the two sheets and were asked to find out which covered more space on the table. Initially, except for one, all the eight students compared either length or breadth of the rectangular sheets. Later they overlapped the sheets to compare them.

Students initially try to gauge area using one dimension, either the length or the breadth of the rectangle, rather than exploring area in two dimensions right away. This indicates that there are two different levels, possibly based on processing load, to the spatial understanding of area. There is a surface, 'first-pass', level that is based on one dimension. The learner moves to two dimensions only when this evaluation fails.

2. For the build-up task, all students did arraying (arranging either in row or column) to get the rectangular structure, for most numbers. Of the eight students, four found that the number of cards in the length and breadth could be found by multiplicatively splitting (factorizing) the given number. These four students explicitly used the multiplication table for the card task, while the other four were unsure about the multiplication tables. For the other four students, the use of multiplication was more implicit. We infer from their actions during the task that they were also using the multiplicative splitting for several numbers. For instance, a student started placing 5 cards in a row when given 35 cards, and made 7 such rows to have a 5×7 rectangle. But when asked whether the rectangle could be started with 6 instead, she said the arrangement will be one card short, without physically checking. She was not able to explain why she started with 5 in the first case, and how she knew about the second situation with 6 cards. But her actions, and the process used to arrive at the result, allows us to infer the use of multiplication table in making the array structure. In some instances, students moved between multiplication and addition while making the array. For instance, one student made 4×3 and 6×2 rectangles

physically with 12 cards, and said 15 cards can make a rectangle (prior to using the physical cards) as “3-5 za 15”. But the same student, when given 10 and 13 cards later, said 3, 7 and 3, 10 are the sides of the rectangle respectively. Another student who said “7-4 za 28” for the number 28, also said 8 squares in length and 6 squares in breadth for the same number of cards, and wrote 8+6=14 and 14×6=64 on paper.

In some cases, students made only the boundary of the rectangle, by arranging the cards along the perimeter of a rectangle, leaving a gap with no cards inside. They were then asked to fill the rectangle. This move seems to suggest that there are two spatial understandings of a rectangle, one with an empty space in the middle, and the other as a fully filled space.

The task also allowed some students to explore rectangles with fractional lengths. For instance, two students cut the cards into equal parts to get rectangles, of which one made a 7.5×2 rectangle from 15 cards by cutting one card into half. The other one suggested a 5¼×4 rectangle for 21 cards and made a 6½×2 rectangle with 13 cards.

Overall, the task showed that students' understanding of the concepts involved in area were implicit, partial and unstable, particularly that of the connection between multiplication and arrays.

3. For the quantitative comparison task, students were provided with a unit card and were asked to compare a rectangle (8 inch x 6 inch) and a square (7 inch x 7 inch). Most students did not use the unit card initially, and were unsure about what to do next. They were either comparing the sheets qualitatively, or asked for a ruler to measure them. But when they were prompted to find the number of cards that can be made out of the rectangular sheet, all the students used the cards to make marks on the adjacent sides of the rectangle. Five students made marks along one of the dimension (length or breadth) and then added that number repetitively along the marks made on the other dimension of the rectangle. The other three students multiplied the number of cards that can fit on the adjacent sides of the rectangle to get the total number of cards. In the initial interviews, most students used the addition method, rather than the multiplicative method.

One student started with a qualitative comparison of two sheets by overlapping the sheets. When he was asked to explain, he compared the extra space left on the sheets after overlapping the sheets, and said that they are equal. He noticed that the width of the space left is one unit in each case. However, the student failed to notice that the extra space of the square can hold 7 unit cards, while the extra space of the rectangle can hold only 6 unit cards.

Overall, these results indicate that the multiplicative relation (factor-based split) used to create arrays in the build-up task was not used much in this task. Also, since they thought of using the unit card only after prompting, it appears that the creation of the arrays in the build-up task did not lead to thinking of a given space as an array.

4. For the extrapolation (or, unit of units) task, students had to extend the idea of area to a larger space. The task explored how students used units to measure the given space. Six students were able to do this task. All of them used the bigger unit to measure a given space. Three of them used the multiplicative relation, while the other three used the additive relation. For instance, one student found that 100 unit-square cards filled an A4 sheet, and a table can be filled with ten A4 sheets. She derived the number of cards for the table by adding 100 ten times, rather than multiplying 10 with 100.

Some students made errors such as placing the A4 sheet lengthwise along both the sides of the table, to get the number of such A4 sheets that could fit into the table. They then got the number of A4 sheets required to cover the table, either by just counting the number of such sheets along the boundary, leaving the inner space, or multiplying the number of sheets along the two dimensions. But the students were not consistent in this strategy, and changed their strategy when asked to explain how they got the total number of (the given square) cards in the table.

When students were asked how many times bigger the table was compared to the A4 sheet, most students were not able to comprehend the question. When the question was reformulated, to ask how many such sheets could fill the table, or how many small unit-square cards could be cut out of a rectangular sheet, they attempted the problem. The 'how many times?' question explicitly looks for the multiplicative understanding of a situation, while the revised framing may or may not be interpreted in the multiplicative term. Multiplicative understanding facilitates the idea of extrapolation, but it was challenging to explore this idea among students.

Overall, these observations seem to suggest that students do extrapolate the array structure to larger spaces, but they find the extrapolation of the multiplication operation difficult, and use the additive operation instead. Secondly, instances like putting a rectangular unit lengthwise along the table suggests that those students do not understand the geometrical mapping required to do this task correctly. This mapping is not a problem when using the square units given in the build-up task. This, in turn, suggests that students' extrapolation of the array structure is not a general one, but is influenced by square units.

Discussion

The most interesting pattern emerging from the results is the various levels of stability in learners' ideas (from task 2) and the inconsistency in the application of ideas learned in the previous tasks (tasks 3 and 4). This pattern of unstable and partial knowledge is better accounted for by our network model of the area concept (where understanding the concept of area requires a coagulation of four different concepts), than accounts that treat the understanding of the area concept as involving a (linear) shift from a qualitative to a quantitative notion of space.

The sequencing of the tasks in a spiral fashion did not entirely achieve the objective of interconnecting different aspects of the area concept, but it helped in revealing some of the issues involved in coagulating the individual concepts involved in the understanding of area.

Finally, from a methodological perspective, the physical and manipulative nature of the tasks provided us with a process understanding of students' thinking and learning involved in the area concept, particularly the use of multiplication in creating the array structure.

Based on Martin & Schwartz (2005), the physical manipulation tasks probably helped the students in understanding the array structure better, but we currently do not have evidence to support this view. More studies and analysis needs to be done to understand this process better.

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Socialising Mathematics: Collaborative, Constructive and Distributed Learning of Arithmetic Using a Chat Application

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We report an exploratory study that examined the educational possibilities through a verbal messaging application (chat), and show that this activity has the potential for effectively teaching mathematical concepts. Communicating in a virtual chat room allows children to become literate, as well as situate themselves in a social environment. Because of the latter possibility, children look forward to this activity with lot of motivation and interest. We modified some rules of the virtual chat room in the Sugar Learning Platform to facilitate development of arithmetic skills like addition, subtraction and multiplication. We present the highlights of this chat room experiment, and outline the insights gained from the analysis of the logs collected over five months from a group of 15 tribal village students (3rd and 4th grade).

Introduction

In a regular Indian classroom, we expect children to become literate, but generally we do not allow them to speak or communicate with each other. In a technology-aided classroom, however, the barriers to interpersonal communication breaks down. Chat is an example of an application that allows the children to communicate. At the classroom level, chat can be used to create peer collaboration and competition. At the individual level, it allows some cognitive processes to be distributed to the physical world, as elements usually recorded in working memory are recorded on the computer screen. This offloading reduces cognitive load and makes collaboration, tracking and feedback more reliable. However, chat introduces the requirement of writing everything down. We present a game that exploits these features, to create a learning, teaching and assessment studio. This study explores what works and why, what doesn't work, and what needs to be added into the chat activity that comes bundled with the Sugar platform to be affective as an educational tool.

We only report qualitative results in this paper, as the analysis of the chat logs is ongoing. Our focus here is a distributed cognition (DC) analysis of the key features of a chat game we have developed. Section 2 provides an overview of the study and qualitative results. Section 3 presents a DC analysis of our chat-based game. We argue that the chat application creates conditions for the social learning of mathematics, which, although is not a popular approach in the teaching and learning of mathematics, shows potential.

Computers in the Wild

The Infrastructure

Our study used a chat application running on a One Laptop Per Child (OLPC) [1] machine. These strong and rough laptops (called XOs) are created specially for children. The chat application is part of the Sugar Learning Platform (SLP) [2], an activity-centered, GNU-Linux based desktop, inspired by a constructionist approach (in contrast to an instructionist approach) to education (Papert, 1993). The XO and the SLP are built by non-profit foundations that do research and development work on using information and communication technologies (ICT) for inclusive education.

Every application in SLP is called an activity, and chat is one among many activities provided by the platform. It is like any other chat application, except for the following key differences. One, it does not need an internet connection, as XOs can directly connect with each other through an ad hoc radio protocol. Second, it shows every participant's entry in different colors of their own choosing. Third, the machines can be named, and the

1 http://laptop.org

2 http://sugarlabs.org

machine names are displayed in the chat (Our machines were named after elements in the periodic table, such as Magnesium, Carbon, Sulphur etc.). We exploited these features to make the chat activity similar to a game.

School and Participants

Our study was conducted in a remote village school in India. The tribal village (Khairat-Dhangarwada in Maharashtra state) has a government primary school where children can study up to 4th grade. Students from three different vadis (hamlets) come to this school. It is a full-day school, starting around 8:30 am and ending around 4:30 pm. The school has 26 students. All of them were given laptops (XOs) by the OLPC Foundation. For the current study, only the 3rd (n=3) and 4th (n=12) class students were selected. Almost all the children in our sample were first-generation learners. With the exception of one or two children who got help at home for studies, the students in our sample did not get any learning support outside of the school. The students' parents either worked in farms or as labourers. Some went to the nearest town for work. The school has two teachers, who teach two grades each. The school's medium of instruction is Marathi. The laptops support Marathi (Devanagari) script, and activities were translated into Marathi. The keyboard also had English and Marathi script printed on it, so that the students could type in Marathi. Elder children (3rd and 4th grade) took their XOs home. The school has a charging station, where the children charged their XOs during lunch break. They were also provided personal chargers at home.

Research Design

Our study ran for five months, and was based on a modified version of the standard one group pre-post quasi-experimental design. The significant modification was that most of the chat sessions doubled up as both tests and instruction (construction), and therefore post-testing was ongoing as the posted messages were used as a source of continuous assessment. Field-notes and computer logs were collected during the intervention. We conducted semi-structured personal interviews to assess students' knowledge before the intervention, and similar interviews were done to check their knowledge after intervention. In both the interviews we checked students' performance in a identification-of-number task (up to three-digit), addition task (up to three-digit) and subtraction task (up to three-digit).

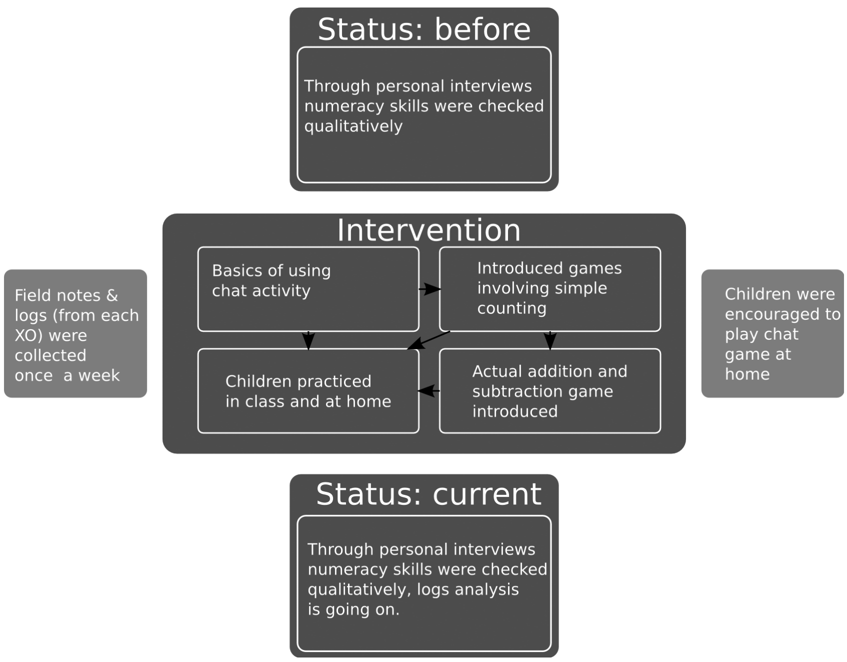

Figure 1. Design of the Study

Figure 1 shows the research design of the study. In the first phase, we taught students the basics of using the computer, as well as the chat activity (although some of them were already familiar with it). In the next phase, we introduced simple games using chat activity, such as counting forward or backward from a given number (e.g. 1, 2, 3, 4, 5,... 100 or 100, 99, 98,..., 1). The aim was to make the students comfortable with the chat activity. During the early phase, the students used to show us their laptop screen when they posted something, not realizing that everyone sees their texts as soon as they post a message. It took a while for them to understand that all screens displayed the same information, and the teacher could also see whatever they were seeing on their screens.

After this phase, we introduced addition and subtraction games. During each phase, students were encouraged to practice what they learnt. Figure 2 shows a typical instance of the chat game (detailed description in section 3.1). Logs from each XO were collected once a week.

Pre-intervention test results

The personal interviews sought to understand the students' reading and writing skills, as well as their numeracy skills. We found that their numeracy skills were very poor. Except for three students, others were able to count up to 100, but eight of these students were not able to identify or write a random two-digit number posed by the researcher. Three students made similar mistakes. When they were asked to write 370, they wrote 30070, a standard mis-conception known as hundred-tens conception (Fuson et al, 1997). They were able to perform simple addition tasks with single-digit or two-digit numbers, without carryover. Five students were not consistent while doing this task. Only one student was able to add three- digit numbers (without carryover). Similar results were seen in the case of subtraction. All students' were able to do single-digit and two-digit subtraction without carryover, but three of them made many mistakes in this task. One student wrote 2–2=2. Only two students were able to solve sums involving subtraction of three-digit numbers (without carryover). All the students were slow in all the tasks, except one student (Magnesium, more on him in section 3.2).

The intervention

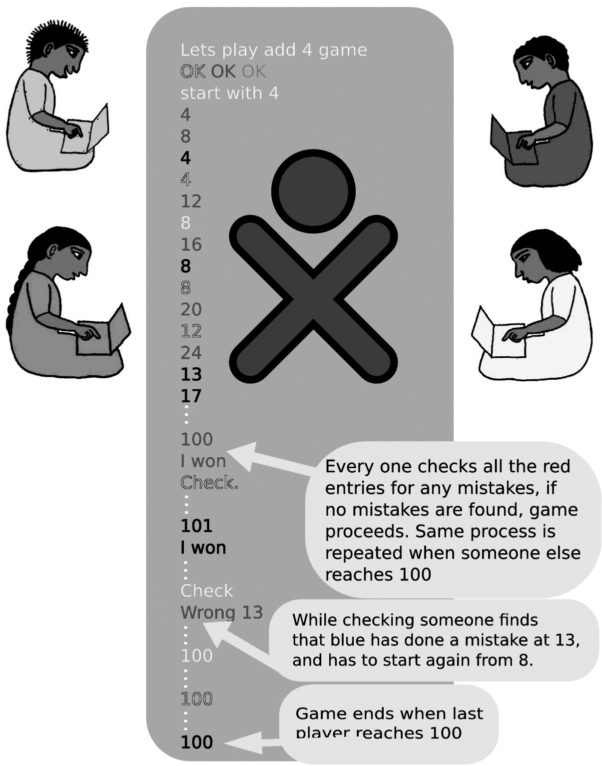

Figure 2. A schematic of a chat session

The interviews showed that students' writing and reading skills were good, but they had little numeracy skills. We wanted to improve their numeracy skills, and also support their literacy skills using the chat activity. Our first intervention involved playing a simple addition game, where a student (or teacher) first proposed a number (say 2), and then another number (say 3) that needed to be added to the first number cumulatively. All the chats happened in Marathi. In this example, the series proceeds in the following way (2, 5, 8, 11, 14, 17....) Each student creates this series by consecutive addition, until a three-digit number is reached. The first student who reaches the three-digit number wins the game (by declaring I WON; on screen, or aloud). The others then check all her entries to see if she made any mistakes. If she made a mistake, she has to start again from the correct element before the mistake. If she completed the series correctly, she goes out of the game, and the others keep playing, and the game continues until everyone reaches the three-digit number.

To start the chat application, someone starts a chat session and others join that session. As students join the chat, every computer screen shows who has joined. The screen shows the name of the joining person's machine, in the color of that machine (Every XO has a unique color, and everything done by that machine carries that color. This allows identifying different machines just by color.). When enough people join the session, the students decide, or the teacher decides, what game they want to play using chat. For instance, as shown in Figure 2, yellow (Y) suggests playing 'add 4' game. Blue (B), green (G) and red (R) agree. The next task is deciding which number should be used to start the game. Here again Y takes the lead and 'starts with 4'. Anyone can start with any one digit number. With this, the race starts. The objective of the game is to reach a three digit number, by repeatedly adding 4 to 4. Students do this addition in a very simple way in the beginning. They look at their last post, add 4 to it by doing mental addition (initially, they used hands to count) and post the answer. For the next addition, they look at this post and add 4 to it.

In Figure 2, R has posted 4, and then 8. B and G also started by writing 4. By the time B and G reaches 8, R has gone up to to 16. R is leading the race, followed by G, B and Y respectively. The game proceeds this way. In between, the students look at the screen, scroll using the mouse and see where they are in the race. The game stops for a moment when someone shouts or writes (when students are not in physical proximity) 'WON' or 'I WON'. In Figure 2, R says 'I WON'. Soon after, someone has to say 'CHECK'. Here G says it. Everyone checks all the entries made by R, by scrolling up using the mouse. They only look for entries in red color, and see whether she has done all additions correctly. If no mistakes are found, the game proceeds. R (the student who won) still participates in the game, but only when someone else says 'I WON'. Then R also participates in checking whether that student has made any mistake. The game again stops when B says 'I WON'. Y asks for checking, everyone starts checking all the entries in blue. Y finds that B has made a mistake at 13 – instead of 12 she wrote 13 – and all the entries following are wrong. The game resumes, and B has to start from 8 again. This process is repeated till the last person completes the game. In between the game, students find their mistakes, either by thinking about their screen entry, or by comparing it with entries made by others. They correct their own mistakes. To keep up with others, and to increase the speed at which they post their entries, students keep one hand over the ENTER key and the other hand on number keys.

Post-intervention test results

After five months of this intervention (3 hours a week), we did a personal interview similar to the pre-intervention interview (n=13). We found that the majority of students had remarkably improved their numeracy skills. Eleven students were able to identify and write numbers up to three digits when the numbers were randomly posed by the researchers. Before the intervention, most were able to only identify and write up to two digits. Their speed in identifying and writing numbers had also increased. Eleven students were also able to solve addition problems up to three digits without carryover. Similar improvement was seen in subtraction tasks. Ten students were able to solve subtraction problems up to three digits.

A preliminary analysis of the chat logs showed that 226 chat sessions were recorded, with the length of individual sessions varying from a few seconds to 20 minutes. Out of these sessions, 96 sessions were conducted when the researchers were present. The remaining 130 sessions happened during our absence. The children were initiating more chats on their own, and this is strong indication that they really liked the chat activity. Anecdotal evidence also supports this view. For instance, before starting the class, we used to ask the students "what should we do today?", and mostly the answer was "lets play chat activity". Also, the students used to be completely absorbed in playing the chat activity, and unlike the case of some other programs in the Sugar platform, we never had to force them to engage in the chat activity.

In the early period of intervention, students used to do simple additions using finger-based counting, which is easy, but takes time and works only for small numbers. After a while, these students started counting mentally. They also used their knowledge from school (multiplication tables), for solving addition problems (see section 3.2). These were significant shifts, possibly catalysed by the competition created by the chat game. To win, students needed to optimize their moves, and school knowledge was useful for such optimization.

The Distributed Cognition of Mathematics

Following Hutchins (1995), we will use a distributed cognition (DC) framework to analyse the role played by the chat activity in our classroom. This framework is suitable for two reasons. One, the chat application creates a socio-technical environment, and DC is currently the best framework to understand such environments. Second, the learning in our case happens through the transfer of representations, across many different modalities, and across a group of learners. Understanding this process requires taking the entire class as a unit of analysis, including the teacher, students and the laptops. DC provides a good framework for such an approach. Kirsh

(2010) also contributed to our understanding of how the structure of the chat activity helped the students and the teacher. In section 2.5 we have provided a procedural description of the tasks performed by the students in detail, particularly what kinds of representations are created, processed and transformed. In the next section, we examine the students' tasks from a cognitive standpoint. Due to space limitations, we do not discuss the teaching advantages provided by our chat game in this paper.

A cognitive description of the student's tasks

There are two kinds of cognitive processes going on in the chat activity. The first is the ones we can see directly, and are outside the individual students' head. Second is the ones we need to infer, involving processes taking place within individuals' heads. While playing the game, the students write a number and post it, creating a persistent external representation that is color-coded and indexed to an individual poster. This persistent representation helps learning in three ways. One, it allows a learner to notice and focus on her own mistakes and difficulties, as well as track her response time, in relation to others' mistakes and response times. Second, it makes it possible for others to contribute to the student's learning (Kirsh, 2010), by pointing out mistakes, and also setting up a peer environment, where the student knows that her mistakes are implicitly judged by others in relation to everyone's mistakes. Third, it sets up a turf for constructive competition, as well as a space for improvement, in terms of both accuracy and time.

To see the advantage provided by this system clearly, imagine a situation without the chat activity, where the game is played by calling out the number. In this case, the structure is not persistent, and therefore it is difficult to keep track of, both by the poster as well as her peers and the teacher. If the game is played by writing on a paper with pencil, it will not be immediately shareable with everyone. If the game is played using a blackboard, it will be immediately shareable but it wouldn't allow the competitive element to form, as the response speed will be affected.

Going to a more detailed level of learning, in the chat activity, the number is written on an external media that is persistent, and this allows the individual student to lower his use of memory space. The same posted number is used for the next addition. The student does not recall the number from her memory, she looks at her previous post and adds to it a number which she recalls from her memory. The number which is taken from the memory (here it is 4, as the game is to 'add 4') is used again and again, and the rehearsal process improves the speed of addition with that number. The complexity of addition also improves, as each instance of addition is with a larger number.

A second important learning event is the comparison between one's own posts and other students' posts, to decide where one is in the race, and/or to decide whether one did the correct addition or not. For this, a student looks at the entries surrounding her entry. The color of her own entry acts as an anchor and filter, and this reduces an enormous amount of cognitive load in processing her rank in relation to others.

A third important learning event is the 'CHECK', when someone says 'I WON'. When students are checking entries posted by that student, the task is a peer evaluation. But this evaluation is easy in the chat situation, as it involves looking for visual similarities (all the entries in that particular color). This checking is very engaged, as every one checks the posts on their own screens, and sees the posts in relation to both timing and accuracy of other posts, and the evaluation is quite deep. An individual learner's understanding of a mistake is thus clearer than possible with verbal, paper-pencil or blackboard versions of the game.

In the above description, the learning processes exploit external representations, which reduces cognitive cost. But there are certain processes in the chat game that do not migrate outside the head, because they cannot be executed outside in this game. One such process is mental addition. This process is important in our case, as we want students to learn to do addition quickly in their head (and say, not on a calculator on screen). The chat activity lowers the cognitive load on each individual in the group, but it focuses the cognitive resources of the group, making them available for learning the mental addition task individually, as well as while acting as a group in helping others learn addition.

Along with addition, other processes also run inside the head, such as: 1) deciding what strategy to be used for the addition task, 2) trying to adopt a new strategy from information collected from looking at others' posts, or 3) trying to find a new strategy. These are precisely the higher-level learning-to-learn aspects that we want to teach students. These higher-level features cannot be triggered by designs without chat, as they do not have the dynamic social and competition contexts that lead to strategy-level thinking. They focus only on addition.

The chat activity thus keeps cognitive resources available for what we want to teach students, and offloads or distributes most of the other peripheral things to the world, outside the individual's head. The activity also creates a social learning situation where the learner automatically moves to a strategy-level of learning. Apart from learning how to add, the activity provides a very rich context, where the children are not only able to focus on their own inscriptions, but also track others' performance. They are able to perform not only self-assessment, but also assess others' performance. Such learning, where students learn to assess others' mathematical ability, and rank their own performance in relation to others' at a detailed level, is not possible with current ways of teaching mathematics.

It is worth noting here that the students learned to read and write better while playing the game. In order to play and win the game, they had to read and write on the screen, that too at a very high speed. While this is a constraint that comes with the media and the externalization process, this constraint also led to students improving their reading and writing skills.

Magnesium: The effects of the social environment

The chat activity is happening in a social environment. The students are interacting with each other, and also with the teacher, while they were playing game. We believe this social environment provides the context for students to improve their mathematical skills, and then discover better strategies for solving problems, so that they can win the game. The same environment also allows them to learn strategies from others. We will illustrate these two points using a significant event that occurred during our study.

The first event is a discovery of a strategy by a student, and the propagation of this strategy through the class. While playing a special version of the addition game, where one number was proposed and the same number was added to it to get the series, we observed that one student (named Magnesium) left others far behind in the race. The change was so sharp that it was immediately noticed. This happened for the next few games as well, But after that, another student named Sulphur caught up with him. Now these two students left the others far behind. Everyone noticed this change. After a few games, many of them were doing additions at a similar speed. We tried to understand what was happening, and asked the students how they were doing the additions so quickly. Magnesium and Sulphur answered that *they were using multiplication tables* (which the students memorize in class) for the repeated addition, and this was the reason for the sudden decrease in response time. This strategy works only when the number to be added and the starting number are the same. For this reason, in the last few games, they were also purposefully keeping the two numbers the same.

Note that this shift is a radical one, given that many of the students started off by doing addition with their fingers. Now, not only can they do the calculation in their head using multiplication tables, they have also learned the connection between addition and multiplication in a deep way, such that they tweak the entire game structure in their favour.

This example clearly shows that students are actively looking for better strategies for optimizing their game performance. In the process, they are discovering patterns and inventing strategies based on what they learn in the classroom. These strategies then propagate through the class. This is possible because of the shareable and persistent nature of the external representations created by the chat activity. When students continuously interact with the external representations, new patterns emerge, which leads to discovery of new strategies. Sharing the strategy using external representations makes its propagation possible (Kirsh, 2010). We have seen similar patterns when students switched from counting with fingers to sequential addition (also see Fuson et al, 1997).

We believe that this discovery and propagation of a new strategy occurred also because of the social environment of the chat activity. Children like competition, and the ‘6 seconds fame’ they get when they win the game. This motivates them to learn or find ways with which they can do the activity faster, and reach the goal before others. Even when someone reaches the goal very late, we have seen them showing similar joy as the winning students. Also, though they want to compete, they were seen cooperating as well. The student who finishes first returns to one of the playing students, and begins to support him to reach the goal. The chat activity thus provides the context for the social learning of mathematics.

Future Work

Data collection in this study is completed, and we are in the process of analysing the chat logs. We expect many important patterns to emerge from the logs, particularly the actual improvement in speed and accuracy over time, and how this pattern spread over the sample. Also, we will look at the multiplication case in more detail, to see how the optimization technique spread through the population. We expect to discover other such cases from the log analysis. These analyses would be able to provide insight into how new strategies are discovered/learned and how they propagate through an entire class. Also, how performance in the activity is related to motivation. These details would help us in designing new activities, particularly a similar chat application we are designing to teach the concept of area.

Conclusion

In this paper, we reported our experience using the chat activity as a social constructionist medium to teach numeracy and arithmetic skills. Our task was designed as a game to motivate students to learn numeracy skills as well as literacy skills. The students learned to use multiplication tables as an optimisation strategy. This experience provides some pointers on ways to design games inspired from close-to-life social context, for not only mathematics but other subjects as well. The study shows that the externalisation of representations can not only offload memory, but also lead to a closer focus on the essential task at hand. The design of the game also provided a quicker feedback to the students by providing them with a self as well as peer-to-peer assessment model. This initial study opens up several exciting possibilities to use a simple simulated game-like social environment for an effective and motivating means of teaching, learning and assessment.

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Marching Towards Inclusive Education: Are We Prepared for Inclusive Science Education?

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The paper reports the historical background of inclusion in education and the status of inclusion in education in India. The article concludes that in spite of several efforts by the Government and other educational agencies in India, the dream of inclusive education for all students with differential abilities-disabilities or belonging to any social or cultural group remains unfulfilled. When focussing on science education, one finds that there is a lack of data on status of students from different marginalised backgrounds in science education, yet from the little data found it is evident that science education is not inclusive. The possible reasons seem to be: lack of positive attitude towards inclusion, lack of institutionalisation of strategies which have been made by isolated educators to make science inclusive, lack of use of adaptive technologies and low expectations in science from students with disabilities.

Introduction

Inclusion is a broad social model of adapting organisational or community facilities and processes to diversity, thus including persons with disability and other vulnerable or oppressed groups. According to the Action Plan for Inclusive Education of Children and Youth with Disabilities (MHRD, 2005)- "In its broadest and all encompassing meaning, inclusive education, as an approach, seeks to address the learning needs of all children, youth and adults with specific focus on those who are vulnerable to marginalization and exclusion. It implies all learners, young people - with or without disabilities - being able to learn together through access to common pre-school provisions, schools and community educational setting with an appropriate network of support services". It is important to note that we have a general philosophical approach that the "fight of one is the fight for all", though in this paper our focus is on the inclusion of students with disabilities in education.

A historical background of inclusive education

The history of the inclusion movement began in India with the National Policy on Education, 1968 (MHRD, 1998), which along with an emphasis on education of girls and backward groups of children envisaged the expansion of educational facilities for children with disabilities through integration in regular schools. This policy was followed by the Integrated Education for Disabled Children programme (MHRD, 1974) to promote education, and ensure retention of children with mild to moderate disabilities in regular schools.

The formal movement of inclusion spread through the Normalization principle, which is based largely on the writings of Mikkelsen, Wolfensberger, and Nirje. This principle suggests that "you act right when making available to all persons with intellectual or other impairments or disabilities, patterns of life and conditions of everyday living that are as close as possible to or indeed the same as the regular circumstances and ways of life in their communities" (Bengt Nirje, as quoted in Billimoria, 1993). This principle was reflected in the Declaration on Rights of Persons With Disabilities by the United Nations, General Assembly, in 1975 in its promotion of *integration* of persons with physical and mental disabilities in normal life.

The initial movements made towards integration of the disabled in education, speeded after the declaration of the year 1981, as the 'International Year of Persons with Disabilities' (IYPD). This resulted in several policies and plans in countries all over the world towards removing obstacles that prevent persons with disabilities from exercising their rights (Tundawala, 2007). Some of the policies and programmes that followed IYPD in India are: Project Integrated Education for the Disabled, launched by Government of India (NCERT 1987), the Programme of Action (MHRD, 1998), the Rehabilitation Council of India Act enacted by Parliament of India (RCI, 1992), the District Primary Education Programme, (MHRD, 1997), the Persons with Disability Act, (MLJCA, 1995), and the Sarva Shiksha Abhiyan (MHRD, 2004).

At the same time there was a shift of focus from *integration* to *inclusion* initiated by UNESCO (1994), through the Salamanca statement on "special needs education to all excluded children in regular schools with inclusive orientation", which advocated the development of inclusive education systems for all children. Finally, it was after the movement on equality of opportunity in education the 'Education for All', (UNESCO, 2000), that "the right to education for persons with disabilities towards inclusion", got established and 'inclusive education' became a terminology used for including all groups of children, those socially, economically or those excluded due to disabilities (Miles and Singal, 2008).

In India, the shift of the educational model from *integration* of children with disabilities to *inclusion of all* can be observed in the National Curricular Framework (NCERT, 2005), the National Policy for Persons with Disabilities (MSJE, 2006), and the National Curricular Framework for Teacher Education, NCFTE (NCTE, 2010), which emphasised the need of making learning environment appropriate not only for children with disabilities but also for all children with diverse backgrounds and needs.

Need for inclusion in education

According to UNESCO (1994), regular schools with an inclusive orientation are most effective in combating discriminatory attitudes, building an inclusive society and achieving education for all. Research studies have demonstrated the effectiveness of inclusion in education practice, the positive effects on the educational outcomes of children with disabilities in inclusive settings (Katz & Mirenda, 2002), and the lack of any significant difference in the development of children with special needs in inclusive and special settings (Lal, 2005). The foreword of UNICEF (2003), focussed on inclusive education in India, estimates that "70% of children with disabilities, including those with mild mental retardation, can attend regular schools provided the environment is designed to be accessible and the institution is willing to accommodate them".

Education and marginalised groups in the Indian context

In India there is confusion about what groups of students are to be considered while focussing on inclusive education. This confusion is exacerbated by the existence of separate Government Ministries to look after the education of children with disabilities (Ministry of Social Welfare) and other children (Ministry of Human Resource Development). Different policy documents in India have used different terminologies for groups of children who find themselves disadvantaged in the education process. These disadvantages have ranged from social, cultural, economic, linguistic or those due to location to gender and disability. The NCFTE, (NCTE, 2010) identifies these excluded groups as children with disabilities of various kinds, or with learning difficulties, and socially and economically deprived groups of SC, ST, minority and other communities, girls and children with diverse learning needs. The UNESCO also identifies marginalised groups of children in education on the basis of remote location, poverty, gender discrimination, disability, language and traditional or cultural deprivation (UNESCO, 2010)

Persons with disability and their education

Persons with disabilities form the world's largest minority group. Around 10% of the total world's population, or roughly 650 million people, live with some disability. And the situation is worse in the so called developing countries, who according to UNDP, house 80% of persons with disabilities (United Nations, 2010). There is a vicious circle or two-way link between disability and poverty; poor people are more at risk of acquiring a disability because of lack of access to good nutrition, health care, sanitation, as well as safe living and working conditions. Once this occurs, they face barriers to education, employment, and public services that pushes them further into poverty.

Total population—1027015247				
Total disabled population – 21906769 (2.1% of total population)				
Visual --48.5%	Movement-- 27.9%	Mental-- 10.3%	Speech-- 7.5%	Hearing-- 5.7%

Table 1. Distribution of persons by the type of disability in India (MHA, 2001)

Three major legislations on disability that have been passed by the Government of India and have been enacted and implemented at both the Central and State level are: the Rehabilitation Council of India Act (RCI, 1992), Persons with Disability Act (MLJCA, 1995), and the National Trust Act (MLJCA, 1999). Education of children with disability has been part of the National Policy on Education and the Programme of Action (MHRD, 1998) but as compared to the national literacy figure of around 65 percent, the literacy levels of the population with disabilities is only 49 percent. Literacy rates for the female disabled population is around 37 percent compared to national average of over 54 percent for the female population and the literacy rates for the male disabled population is 58 percent compared to around 76 percent for national male average literacy. According to the National Sample Survey Organisation, (NSSO, 2002), of the literate disabled population only 9% have completed secondary and higher education. Table-2 presents some numbers on the education of persons with disability.

Category of disabled children	**Number**	**Source**
In school going age	3430000	Census India, 2001
Children with disability having access to education with appropriate support	137200 (4% of the above)	MSJE (2010)
Disabled youth in age range to attend Universities	3160000	NCPEDP (2011)
Disabled youth in Universities	37920 (1.2 % of the above)	NCPEDP (2011)

Table 2. Status of education of children with disabilities

Need of inclusiveness in science education

The constitution of India has acknowledged the significance of science for a rational and egalitarian society. Reflection of this acknowledgement is seen in the Article 51A (h) of Indian constitution, which makes it a fundamental duty of every citizen "to develop the scientific temper, humanism and the spirit of inquiry and reform" (Indian Kanoon, http://www.Indiankanoon.org /doc/560422/). Education for all and equal opportunity in employment is guaranteed by the Constitution of India. Article 21A: Right to Education (RTE) places the responsibility on the State to provide, "free and compulsory education to all children of the age of 6 to 14" (MLJ, 2009), thus, making education a fundamental right in India. The constitution also gives all its citizens a fundamental Right to Equality through Article 15 (i) and 25 (ii.b) for social equality and equal access to public areas which includes all schools and colleges maintained by public funds. Article 16 (i) guarantees equality in matters of public employment, while for promotion of social justice, Articles 16 (iv) and Article 335 allow reservations in favour of backward groups in all public services (Indian Kanoon http://www.indiankanoon. org/doc/1942013/, /631708/, /250697/ & /1113850/).

Status of Inclusiveness in Science education

Despite a constitutional obligation for scientific literacy in India, science education acts as an exclusionary device. The criteria of high over-all percentage in class X to get admission to science course in junior college disproportionately filters out many children from lower socio-economic levels. The use of English as a medium of instruction of science after class X in many parts of India creates an elitist language barrier. That limited number of schools offer science after class X and that these are often located in select urban locations and are also elite private schools creates another filter as do the poor facilities for science learning in schools located in rural and backward areas at elementary and secondary level. Besides, the lack of supportive facilities hinders science education received by children with disabilities and impairments. Even after 60 years of the Indian Constitution, one can easily find instances of unequal access to science education in India. According to some science educators the elitist nature of science education tends to exclude (Fensham, 1986). As described by Aikenhead (2009), p. 1, "Science and technology education in schools has traditionally served an elite group of students" and the elitist nature of science discourages marginalised and low achieving students to opt for science for their higher studies.

The India Science Report (Shukla, 2005) states better employment opportunities are available to persons with higher qualifications in science and related courses, thus, the constitutional obligations for equity actually remain ineffective due to the lack of access to science education among the weaker sections of society. The National Policy of Education, 1968, (MHRD, 1998) acknowledged the role of science education in accelerating the growth of national economy, and recommended science as an integral part of general education till the end of school stage. Extending the efforts of previous policy, the NPE 1986 (MHRD, 1998), made efforts to "extend science to the vast numbers who have remained outside the pale of formal education" by curricular reforms. But all these steps are insufficient due to lack of focus on the issue of 'Science for All'. A decline in enrolment in science education at the higher levels has been reported (Mukherjee & Varma, 2001 and Garg & Gupta, 2003). Interpreting the findings of the India Science Report (Shukla, 2005) provides reasons for the decline. The Report states that at the +2 level, of the students who did not opt for science, 10% said that they did so because science is costly, while another 45% found science uninteresting. This points to the ineffectiveness of the attempts to make science accessible.

Barriers to inclusion in science education

Attitude

Students from various disability groups have been found to suffer from low expectations from teachers, parents and societal members, thereby creating a poor self concept in them regarding science education (Fraser & Maguvhe, 2008). A common attitude among educators, parents, and peers that 'they cannot study science' is the foremost barrier to inclusion in science education. UNESCO (2010), identifies public attitudes as a barrier to equal education of people in India. Research indicates that negative attitudes towards persons with disabilities may lead to low expectations which in turn can lead to reduced learning opportunities (Sharma, Forlin, Loreman and Earle, 2006). Researchers have found that educators having relatively positive attitudes towards inclusion of children with disabilities also have a reasonably good knowledge and relatively low concerns about it (Changpinit, Greaves & Frydenberg, 2007). Sharma, et al. (2006) suggest that additional training and/or experience with disabled persons leads to development of positive attitudes in pre-service teachers towards people with disabilities and more confidence in implementing inclusive practice.

Educational aspects

An education system focussed on competency in learning of 3R's cannot move further to the learning of products and processes of science through experiential learning, thus leaving behind a large section of learners marginalised. In the case of parents of children with disabilities, the "distrust in both the special and mainstream education systems" leads to forcing them to keep their children at home "for fear of their abuse or neglect in the classroom" (Giffard-Lindsay, 2007). In some states of India, the medium of instruction of science at senior secondary level has formally been declared to be English, which may create a strong cognitive barrier for students from marginalised groups. The need to learn a foreign language in order to learn science creates an extra cognitive load on students.

Lack of adaptive technology

Students with disabilities generally have different kind of learning needs, modes of perceptions and preferences, so a modified "access to content materials that are consistent with their learning preferences and needs" (Broderick, Mehta-Parekh, and Reid, 2005) are needed to be used in science classrooms and laboratories. Such adaptations may include use of adapted laboratory equipments with tactile markings, providing hearing or speech aids to students, provision of a facilitator to support a student's access, use of audio-recorded texts; Braille, large print materials, tactile marked graphs, models or diagram, peer support, additional time, fewer items or questions to address, multi-modal presentations etc. But a general survey of Indian classrooms shows a marked shortage of such resources.

Classroom factors

The World Bank (2009) has stated that in India the quality of public secondary education is "alarmingly low". Some factors for this state of affairs are the high teacher-pupil ratio in science and other classrooms, lack of physical facilities and inclusive infrastructure for those with disabilities, lack of training to science teachers either pre-service or in-service, to "address the learning needs of all children including those who are marginalised and disabled" (Julka, 2012), lack of pedagogical research for effective teaching in inclusive settings, lack of inclusive culture and inclusive practices in schools, lack of "knowledge base about various impairments... and how it effects the learning process" (Auluck, 2012) and lack of special co-educators in schools. Gillies & Carrington (2004) point to a dire need to review the attitude, organisational structures, curriculum and pedagogical practices of science education to guide a transformation regarding inclusion of all children.

Possible effects of inclusion

It can be envisaged that putting a thrust on inclusive science education would not only be beneficial to the career of students with diverse cultures and learning needs, but also to the science education, science and thereby to the human society. Inclusion is not merely a way of education, rather it is a way of progress of humanity which considers the benefit of all. Moreover, by bringing new dimensions of cultural and sensory perceptions into science a more holistic and lively progress may get boosted up in science. The only need here is to implement the body of research in inclusive education from the initial stage of planning education be it curriculum, infrastructure, training or the social aspects of education.

Taking an extreme stand: Can students with visual impairments be included in science classrooms?

Researchers have undertaken various steps to answer the above question. Hill (1995) in her study concludes that with ingenuity, a little money and much time, even students with visual impairments can be given nearly full access to the practical and diagrammatic aspects of science, thereby improving the quality of their education. Beck-Winchatz & Ostro (2004) acknowledge the inaccessibility to graphical materials to be a major obstacle confronting blind and visually impaired students in their science education. They report the effective use of three-dimensional scale models of near-Earth asteroids to teach space science to blind and visually impaired students through hepatic perception. Fraser & Maguvhe (2008) in their study emphasise multi-sensory approaches, learning mediation aids and curriculum adaptation for teaching science to learners with specific disabilities. Kumar & Stefanich (2001) in their paper suggest various strategies through examples from different levels of education to make general science classrooms and laboratories inclusive.

Conclusion

An inclusive science education, which although is not a key to success, ensures an enlightened citizenry capable of making rational decisions. To make the Right to Education a real success, science education should be given a boost by making it all inclusive. The research body exemplifies that inclusion in science is possible but the statistics give evidences that in spite of several efforts made towards achieving inclusion in education, the inclusion movement in India has not yet lost its inertia. It is most imperative to focus on what are the barriers to inclusion. The discussion in the paper proposes that science education can be made inclusive- through development of positive attitudes towards inclusion in science, improving academic environment in classrooms, systematization of strategies to make science education inclusive, use of adaptive technologies and raising expectations of students who have disabilities as well as societal expectations.

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Projects in School Learning: Teacher Experiences

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According to recent curricular policies guided by National Curriculum Framework 2005, projects have been incorporated in students' formative assessment. However, little care has been taken to survey the teachers' actual project practices and ideas about projects before making it mandatory for all school subjects. Our study explored four teachers' views about projects and some aspects of their project practices through semi-structured interviews and reported here. It is found that although teachers are primarily dictated by policy guidelines to conduct projects in their respective subjects, teachers' own views on projects and understanding about learning decides the way projects are structured and implemented. Teachers do not use projects to teach textbook content, but to reinforce it. They face several difficulties in implementing projects meaningfully, though some potential opportunities are missed due to their limited view towards projects and learning. The insights from the study formed the input to structure collaborative workshops for teachers to develop Project Based Learning modules for middle and high school students.

Introduction

Research has shown that practices of Project Based Learning (PBL) lead to positive changes in teaching and learning. They have been shown to improve the school climate, students' attitude towards learning, performance and work habits, students' problem-solving abilities, self esteem and motivation (Thomas, 2000; Ross and Lowther, 2003), and their understanding of subject knowledge (Boaler, 1998). PBL is shown to improve critical thinking and collaborative skills (Scott, 1994), design proficiency, controlled experimentation, measuring skill, and the ability of students to generate their own questions to guide their scientific inquiry (Barron et al., 1998).

There is no single accepted definition of PBL in academic literatures. In our study we have adapted Thomas's (2000) five criteria to characterise PBL. According to Thomas (2000), PBL is a model of teaching-learning that organizes learning around projects. In PBL, projects are not trivial tasks; they are complex tasks based on challenging questions or problems which involve students in design, problem-solving, decision making and investigative activities (Krajcik et al., 1994, Barron et al., 1998, Thomas, 2000). Depending on the focus of a teacher or a school system, projects take on different formats in different school environments. Above all, teachers' ideas about and attitudes towards subject content, student leaning as well as projects are likely to influence how projects are conducted, and whether and how students are assessed.

Teachers' views

Teachers' ideas about projects and assessment are based on a complex interaction between their concepts of learning and philosophical understanding of education. Their conduct of projects also depends on their knowledge of content and pedagogy.

In a study of the views of Turkish primary school science teachers about the issues related to practice of PBL, Dogan et al. (2011) report that the teachers attributed several positive aspects to PBL. Teachers of different subjects worked together on projects, and found that the funds and library resources were adequate. They were, however, confused about the adequacy and arrangement of computers and material resources in their schools. When asked about students' practices and preferences, the teachers responded that students communicated, worked in groups, effectively used educational technology and engaged in creative activity. Their individual academic differences caused no problem in PBL. They were unsure about students making efficient use of resources and whether they could learn on their own.

Teachers in India do not seem to use a set of consistent criteria while conducting projects with their students. Their projects rarely address the prescribed syllabus, or assessment of students' learning. The few reports prior to the commencement of National Curriculum Framework (NCF), 2005 (NCERT, 2005) related to Indian teachers' views on projects have focused on the limitations of teachers in implementing environmental projects outside the regular school curriculum (CEE, 1997). But the new curriculum has explicit recommendations for teachers to carry out projects as part of the curriculum. Such curriculum policies can have an influence on the nature and structure of projects in school.

Policy drive for Projects in Indian education

Following policy suggestions in the NCF 2005 to introduce projects in the school curriculum, there is a renewed interest in projects in Indian schools. Several teacher professional development programmes in different subjects organised around the country in response to this policy, introduced the ideas of (a) constructivism, (b) continuous assessment and (c) school projects. Unfortunately, this has resulted in considerable confusion among teachers, school managements and parents about all three aspects, besides problems of responding within a short time to policy suggestions.

A possible strategy to address change in classroom transactions could have been through increasing teacher empowerment. This may be achieved by working in collaboration with teachers, to develop pedagogies that will suit their classrooms, and by listening and responding to teachers' voices (Shome and Natarajan, 2010). The study reported here is part of an initiative to listen to teachers, and use their experiences in developing project pedagogy in collaboration with them.

Method

The research programme was initiated with individual surveys of four teachers using a semi-structured interview format. Teachers' practices of and ideas about projects were probed. The findings from the four individual surveys are reported here.

Objectives

The objective of the study is to gather four teachers' views and practices and analyse their experiences of conducting projects to see how these are connected.

The four teachers

All the four teachers were female who taught at middle and/or high school levels – namely Class V to X. They taught in English medium schools, but used Hindi also to convey ideas. The teachers' profiles including their educational qualifications, years of teaching experience, the School Boards that defined the curricular materials, and average number of students in their classes are given in Table 1. Three of the teachers - AB, DB and AM – taught science, while CS taught history, geography and Hindi (subject).

Name	Educational Qualifications	Experience (in years)	Board/ Institution	No. of students in each classroom
AB	MSc, BEd	30	Maharashtra State Board	70-80
CS	BA, BEd	20	Government, autonomous, CBSE	40-45
DB	MSc, BEd	18	Government, autonomous, CBSE	40-45
AM	MSc, BEd	2	Private, CBSE	40

Table 1. Teacher profiles

Interview Survey Instrument

An interview protocol was developed to capture several aspects of teachers' existing practices of school projects: motivation for projects, their perceived goals, and planning and implementation of projects. Semi-structured interviews ranging from 30 to 55 minutes were conducted among teachers. Teachers' perceptions of benefits of projects and challenges faced in conducting projects were probed. The interviews were audio recorded, transcribed and checked for punctuation. These were checked against researcher's observation notes. The data was analysed as described below.

Analysis of interviews

The responses of each of the four teachers were categorised under one or more of three broad themes listed below. Each teacher's responses are discussed in the context of the subject content addressed by her projects, her expectations of students' learning and her own understanding of PBL.

1. Influence of policy guidelines on teachers' motivation to do projects,
2. Goals of projects perceived by teachers, and
3. Project planning and implementation - (i) assigning tasks to students, (ii) expected outcomes of project, (iii) nature of guidance, (iv) resource use, and (v) aspects of assessment.

Results And Discussions

Influence of policy guidelines

Policies at the School Board, or local School levels are expected to influence teachers' practices. All the teachers in the study noted that there was a recent increase in the number of projects in all subjects due to new policies. In fact, AM attributed projects directly to her school guidelines, while AB had guided students on extra-curricular projects in 18 out of her 30 years of teaching experience, beginning long before the current policies came into force.

AB, the State Board teacher, conducted projects with students of Class VIII to X, while DB and CS, who were from the same CBSE school, conducted projects at all levels (Classes V to X). AM, though from a CBSE school, reasoned that in Classes IX and X, students did not need to do projects as they already engaged in *practicals* (laboratory work). Besides, students made models with explanatory charts to present in the government mandated science exhibitions around the country, or at school exhibitions.

The frequency of projects depended on school circulars and teachers' own teaching plans. AM conducted one project as part of each of the six unit tests in the academic year. AB's project frequency was annual, and for either an examination or an exhibition. DB and CS did not have any set frequency for their projects. Thus, policy guidelines seemed to motivate teachers to conduct projects, but did not change project structure, or connection to student learning.

Goals of projects

Teachers' pedagogical philosophy influenced their perception of the value and utility of projects. In fact all the teachers in the study believed that projects were not suitable for all students. While three of the teachers felt that academically serious students would perform better in projects, AB felt that some students irrespective of their academic performance are motivated to do projects.

"Why should teachers engage students in projects?" elicited different answers. AB's primary focus was to inculcate research ability among those students who were already interested in doing projects. On the other hand, DB, CS and AM conducted projects after teaching the related topic to improve the understanding of a topic among their students. DB and CS felt that projects on textbook topics generated students' interest, and may even help improve their performance in examination. Colleagues DB and CS equated an activity like writing or drawing to short projects. They also assigned projects during a lesson that would encourage students to obtain additional information on the topics. On the other hand, longer projects of AB and CS were linked to more than one topic or subject. DB observed that students performed better in projects when they had already learned the lesson.

> "...So exciting things are done in the class to create their interest in science... whichever lesson we are taking up that month... we choose the activity... So that they are comfortable. Before doing anything they should know what they had to do, otherwise... if it is not clear in their mind... they won't able to express what they want to. They can do better (in projects), actually... after learning (in class)..." (DB)

CS, the social studies teacher, planned activities and projects for topics, which she thought were difficult for students to remember or understand. She felt that longer projects would be more engaging.

> "I am asking them... because these things (project topics) are for their examinations also... ...so that they may be able to read the textbooks and would be more interested to do this work." (CS)

AB, who focussed on research abilities for suitably inclined students, assigned projects in environmental science that required students to go beyond the textbook content. Her projects to all students, often given towards year end, were not to teach content. She also guided select students on government sponsored national level project competitions.

Teachers mostly assigned projects after teaching in traditional ways to motivate students to read the textbook and perform better in examinations. Their projects involved application of what was taught and had no novel textbook content to learn. When a teacher went beyond the textbook while assigning projects, it was either to serve a requirement for a board examination or was meant for a few select students to participate in competitions.

Project planning and implementation

The outcomes of a project depend on how the project is conducted. Conduct of projects included aspects like setting learning goals for students (discussed above), the extent of specification and nature of tasks, the outcomes expected from students in terms of productions, supports to students by teachers' scaffolding, use of resources, and the way students' productions or their learning had been assessed.

Assigning project tasks

Teachers assigned either well-defined or open-ended tasks, but more often the former. AM assigned only well-defined tasks, while CS's projects were either. Interestingly DB and AB, both science teachers, posed questions with open-ended possibilities to students for initiating their projects.

> "What is the effect of artificial light on plants growth?" (AB, Class VIII)

> "Make a home-made fire extinguisher to be used in our lab, houses etc. What types of acids and bases are you going to use, and how will you make the extinguisher?" (DB, Class X)

Some teachers preferred to conduct individual projects and others preferred group projects. All the teachers including AB conducted group projects for exhibitions. DB always conducted group projects in her class with groups of three to five students, AM and AB conducted only individual projects in class and CS conducted both individual and group projects. Teachers preferred to assign tasks with well-defined result to individuals especially when they had to give marks to students. This is also seen in their views on project outcomes.

Expected project outcomes

The interviews with teachers revealed that teachers encouraged students to come up with tangible products. Students were supposed to do one or more of the following tasks: collect samples and/or information, solve a problem, make a presentation in class, write a report, and make a working model or making an actual product. In most cases all the teachers asked their students to collect sample or information on specific topics. AM assign only this kind of projects to her students. In several cases the collected information needed to be submitted in the form of a written report.

For exhibition purposes all the science teachers expected their students to make a working model. While DB organised students' presentation for all projects, CS did so rarely. On the other hand, most of the exhibition projects by AB were about problem solving, where students had to do experiments, come up with possible solutions or demonstrate a solution. But her projects for examination were individual, where students had to write a report on a given topic. In several cases DB asked her students to make an actual product, like preparing natural indicators of acid/base (project given to Class VI students). Project outcomes are closely tied to teachers' perception of the role of projects in the curriculum, teachers' confidence in evaluating the outcome, and its exhibition value.

Scaffolding and guidance

Students did not receive much help from AM, DB, and CS on projects assigned as home work. Teachers acknowledged that in most cases parents helped students in making the project report. Teacher AB stated that she did not have time to help her Class IX and X students in their school projects. On the other hand, she claimed to guide externally sponsored projects, where she assigned tasks, guided activities, collected resources, communicated with experts and arranged visits to laboratories when needed. DB extended her help to students in class. Both AM and DB helped students with accessing sources of information and suggesting changes in students' productions. Projects were perceived more as addressing a curricular requirement, at best as a motivation to learn, or for mere exhibition of "talent", rather than as a teaching-learning strategy.

Resource use: Materials, facilities and expert inputs

For three of the teachers – DB, CS and AM – material resources were not a constraint for projects. Often students were expected to bear the cost of materials used for projects. Only AB expressed her concern over this issue. Interestingly, AB's school reimbursed the expenses if the project got selected in a competition.

Teachers had mixed opinions about the role played in projects by resources such as access to library, laboratory and the internet. All the teachers found that students collected information primarily from the internet. AB lamented that her students "do not read books". She also felt that this made the library redundant, while the laboratory was more important in conducting science projects. On the contrary, DB felt the need for a library for collecting information, and did not need a laboratory. For AM, who focused on collecting samples and information, and CS, the social studies teacher, both the laboratory and library had little role to play in projects. Only AB felt that for conducting projects, schools needed help from experts, for example, guidance and access to sophisticated laboratories.

How students are assessed

Teachers expressed different views on what to assess and how. The Maharashtra State Board prescribes certain criteria for project assessment: novelty of topic, quality of content, creativity, quality of display, students' own contribution in the work and performance in oral test. AB stated that she had to use these for assessing student projects.

CS used self-developed rubrics for project assessment with the following criteria: properly drawn and labelled figure, "good" handwriting, and use of colours in suitable combination. Showing students' production on "natural disaster," she elaborated that:

> You can find easily the differences between these two... drawn, and coloured it also. Writing is not good... colouring is not good... he is getting 'A'... Otherwise will get A+. (CS)

The students of both AB and CS received an aggregate score on projects, and did not get to know their strengths or weaknesses.

Like CS, AM had self-generated criteria like being neat, attractive, systematic, quantity and correctness of information, etc. However, AM gave feedback to students upon project submission and even asked for modified resubmission. DB assessed students' understanding by asking them questions while they presented their projects. AB mentioned that assessment of students' completed production was an easy task, but it was impossible to assess the process.

> "Assessment is not much difficult. ...They (teachers) do not need time... If you ask teachers to assess the projects, they will ask four questions, and assessment is done..." (AB)

Except DB, all the three teachers relied on finished products to assess their students. Teachers often focussed more on aesthetics and show (exhibition) than quality of content in the project, even when it is stated as a criterion. They rarely assessed student learning through process.

Summary of Results

Resources, class size, lack of teacher strength, and unmatched public expectations are perceived to constrain teachers to traditional methods of teaching (CEE, 1997). However, all the teachers in this study did not state all these factors as major constraints.

Projects were conducted in both Central and State Board schools at the middle and high school levels as part of the regular teaching and learning largely driven by educational policies at school, State or national levels. However, the frequency and structure of the projects were shaped by teachers' ideas of what are projects, their conception of pedagogic strategies, students' abilities, and the role of projects in learning. Teacher AB considered projects as a vehicle to foster the research ability among the motivated students, while the other three teachers relied on projects to motivate students to read content, develop students' ability to remember or perform in examination. Hence, they all structured their projects to address textbook content.

Three of the four teachers (AM, DB, CS) preferred to conduct projects after teaching the content. That is, their projects supplemented classroom teaching, and did not replace it even partly. AB felt that projects would foster learning of varied content, concepts and skills only among some students, and it was "impossible" to expect it to serve all students. Teachers used the term project for all sorts of activities including "collect and paste" activity for middle school students. Teachers rarely posed problems, and if they did, only for introducing projects.

DB and AB frequently structured group projects, CS reported that her students were disinterested in doing group projects, and AM did individual projects. DB used projects, though rarely, for creating a community of learners in class by organising student presentations and discussions of projects in class.

Teachers' ideas about students' assessment were diverse. DB considered questioning as only assessment tool, while the assessment criteria of the other three were not accessible to students. However, DB and AM provided feedback to students during their project and perceived projects as opportunities to support students and explore their difficulties.

Teachers acknowledged that parents often helped students in their projects. Teachers' help was given in finding information sources or resources, when students did not find them on the internet, which they often did. AB perceived monetary, laboratory and expert help constraints in doing projects. A similar finding is reported in a study by Edelson et al (1999), where they explored the "opportunities and obstacles presented by scientific visualization as a technology to support inquiry-based learning." They developed a series of "scientific visualization environments and inquiry-based curricula" and tested in "laboratory and public school classroom settings". The concerns raised by teachers included managing time in conducting projects in a large class size similar to the concerns raised by another study (Blumenfeld et al., 1994). The study reported five teachers enactment of project based instruction in their science classrooms.

Three teachers (AM, DB, CS) felt that projects having open-ended question were unsuitable for many students, and only "good students" could do projects well, while AB quoted several instances of low performing students doing "wonders" in projects. Design and Technology (D&T) projects conducted in the Indian context have included several aspects of PBL pedagogy: the design problem was set in the real world context, the project was goal driven, and it was structured to allow student autonomy (Khunyakari et al., 2007; Mehrotra et al., 2009; Shome et al., 2011). However, these were not conducted by regular teachers.

The study reported a preliminary analysis of the interview of four teachers on their ideas and practices of projects. This study provides an overall picture of four teachers' practices of projects that reflects their position on projects. The findings helped plan and structure a series of PBL workshop for teachers, which addressed development of projects with increased student engagement and autonomy as well as meaningful assessment and feedback.

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Collaborative Undergraduate Biology Research: Re-Structuring Undergraduate Biology Education in India

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This work is an effort to convert undergraduate college laboratories into contemporary, open-ended interactive, inquiry-driven and collaborative research laboratories and hence bridge the gap between practice and theory of biology.

The programme Collaborative Undergraduate Biology Education (CUBE), as the name suggests, is an invitation to young researchers at the undergraduate level into the nature of scientific inquiry through its essential component of collaboration. Our aim is to design 'functional learning ecologies' by means of simple model systems to facilitate collaborative undergraduate research in the frontiers of biology.

"Education should not be something we do to our students: It must be something we do in collaboration with our students" (Brewer & Smith, 2011).

Introduction

The rapidly advancing frontiers of biology research and the changing nature of biology resulting from it, have called for some serious action to be taken to transform the nature of biology education. The undergraduates need to be prepared for the challenges posed by the changing ways we think about and engage in biological research, while opportunities for investigating questions, which otherwise could never be addressed, are becoming possible due to emerging technologies (Luck, 2009). There is a strong need to first accept and subsequently ensure that the biology we teach authentically reflects the biology we do. The 21st century biology undergraduate needs to engage in authentic biology research and integrate the research experiences and skills acquired into understanding, solving and making informed decisions on complex problems related to biology and those encountered in their daily lives (Brewer & Smith, 2011).

The 21st century biology requires that undergraduates learn to integrate concepts across levels of organization and complexity and that they synthesize and analyze information that connects conceptual domains (*ibid*). Teachers, educators, researchers and curriculum planners need to view teaching from an approach that captures the spirit of the nature of scientific practice and to look for concepts that communicate to each other because it would make more sense to communicate the generalities and encourage students to discover their applications through well-designed laboratory exercises (Bialek & Botstein, 2004).

The challenge, however, is to keep the undergraduate classroom current and dynamic without making it overwhelming; to excite undergraduates with the current cutting-edge discoveries and at the same time finding the right balance between the depth of coverage required for conceptual understanding and the factual knowledge needed for the same. This may need a restructuring of the current undergraduate biology syllabus in many ways. One of the productive ways to strike this balance is to revamp the undergraduate biology by integrating research with teaching; making undergraduate research a meaning-making experience (Jenkins et al., 2007).

A growing body of literature has found a link between student research and lasting learning (Bender, et al., 2009, Petrella & Jung, 2008). In a survey (Lopatto, 2007) of more than 2000 undergraduates at 66 universities (Survey of Undergraduate Research Experiences [SURE], students described the research experience as having lead to considerable gains in their "understanding of the research process," "readiness for more demanding research," "understanding how scientists work on problems," "learning lab techniques," "tolerance for obstacles," and various other research areas. The gains persisted even 9 months later when the same students were surveyed, suggesting long-lasting benefits of research experiences (Lopatto, 2007, Hunter et al., 2007, Laursen et al., 2010).

In order to inspire and further solidify the interest of undergraduate biology students in making career choices in biology they should be given an opportunity to experience the allure of the research scholarship. Their participation in such pursuit will improve not only their ability to understand how biologists conduct research but will also prepare them to evaluate scientific claims in their day-to-day lives. This rightly falls under the mandate of "The Vision and Change: Call for Action" report, which discusses the need to develop *biological literacy* to prepare the coming generation of biology scientists, educators, and informed citizens (Brewer & Smith, 2011).

Hands-on research cultivates scientific thinking, giving students authentic research experiences including designing experiments, interpreting unexpected outcomes, coping with experimental failures, considering alternative methodology, testing new techniques and many more (*ibid*). These experiences go beyond the *apprenticeship model*[1] and such outcomes can never be expected to be a part of any regular college laboratory.

The undergraduate biology research environment thus forms a rich learning ecology with student-centric features. The typical features of such an ecology is that it is open-ended, interactive, inquiry-driven, cooperative, collaborative, and context-bound. Without any doubt, the research experience will have high levels of student–student and student–faculty interactions, ready connections of the subject matter to topics of student interest and relevance, learning that reflects aspects of scientific inquiry and most importantly learning progressions designed from the efforts of an ongoing students feedback to the teacher as well as their peers (Wood, 2009, Laursen et al., 2010).

Linking teaching and research will help to bring the processes of research into teaching and can support students in the development of a variety of specific as well as general skills. It can also benefit institutions to build a research profile and thus encourage networking with other institutions and research groups. Further a community of biology educators/researchers will be built, who are willing to integrate evidence-based practice into their teaching. Platforms like an online portal will provide an overview of the pedagogic practices and the reasons for adopting a particular practice (Jenkins et al., 2007). It is very important that the *mutually synergistic communities* of biology teachers/educators and biology researchers work together in order to meet the common goal of student-centered learning.

Indian Undergraduate Scenario

Undergraduate biology research is conspicuous by its absence in colleges and universities, in India. This results in the unfortunate event of what is being taught in the class room reflecting little of what actually happens in the contemporary research field. Overall, in a world propelled by knowledge and knowledge economy, there is this curious case of science becoming less and less attractive an option for the burgeoning number of youth in the country. This, surely, calls for our immediate attention. The biology graduates are entering universities with only a traditional descriptive model of the subject and are unaware of the need and importance of research in connecting theory in biology to its practice. Moreover, biology graduates are often seen changing streams as they are not motivated and find themselves inadequate to pursue career in research.

Diagnosis: An alternate Social Network Model

Conventional social scientific studies "assume that it is the attributes of *individual* actors whether they are friendly or unfriendly, smart or dumb", lazy or industrious etc. that matter. On the other hand, "social network analysis produces an alternate view, where the attributes of individuals at a given time are less important than their *relationships and ties* with other actors within the network" (Global, 2010). Hence, rather than treating individuals (persons, institutions, etc.) as discrete units of analysis, it focuses on how the structure of ties affects individuals and their relationships (Watts & Strogatz, 1998). See fig 1. below. (Figure not visible, please provide correct format)

One characteristic feature that stands out in India, in the sphere of science in general, is the absence of any conscious collaborative approach as a means for strengthening the scientific pursuit. Institutional mechanisms for this are lacking. Hence, we witness several scientific bodies working largely in isolation or with almost non-existent functional networking among them. The absence is all the more pronounced in research collaborations between undergraduate colleges and research institutes in India, unlike in the west.

1 This model is taken as a contrast to the CUBE initiative and is explained as one that assumes a passive transfer of skills in a traditional, closed and individualistic laboratory investigation.

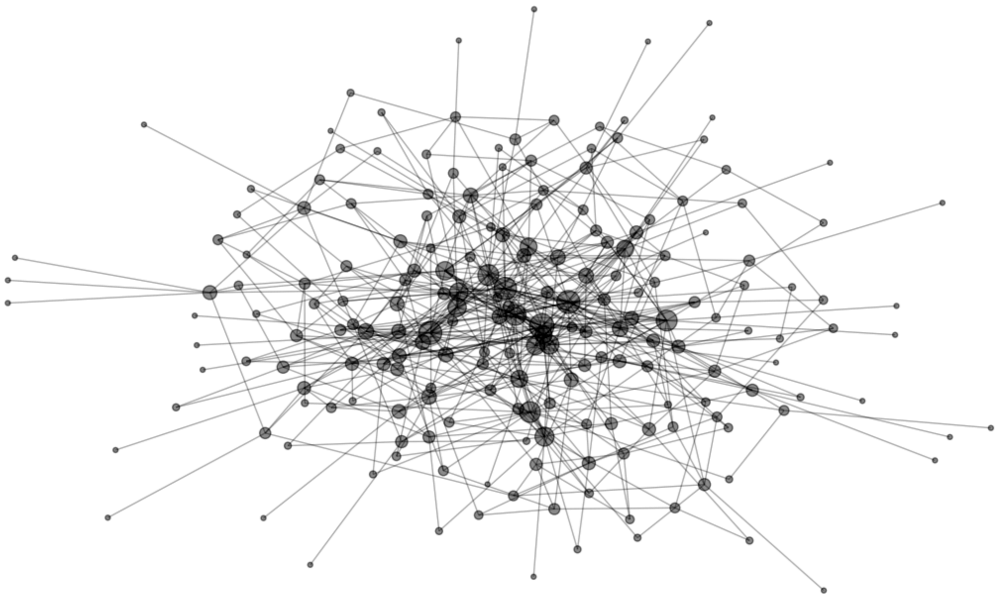

Figure 1: Topology generated using Parallel Global Multiobjective Optimizer (PaGMO1.1.4)[2]

An example of a network inspired by the Small-world Network Theory. The bigger nodes are the members with high connectivity. They link the many different smaller nodes through functional networking; allowing for large amount of mobilization. So even when most nodes are not neighbors of one another, they can be reached from every other node by a small number of hops or steps. The model belongs to a class of scale-free networks and incorporates two important general concepts of growth (number of nodes in the network increasing over time) and preferential attachment (greater connectivity ensures greater receptivity for new links). The model therefore, explains the empowerment of individual nodes by offering opportunities to alter the structure of their ties and relationships.

Remedy: Establishing Functional Linkages between Colleges & Research Centres through Collaborative Undergraduate Research

Our suggested remedy in this proposal is to restructure the relations between the large number of existing bodies by actively facilitating the formation of functional networking among them. We, therefore, propose a scheme that is aimed at empowering existing teachers of more than 26,000 colleges and 504 universities in the country, enabling them to functionally network among themselves and with research scientists, through a large number of collaborative undergraduate research programs, using among others, the state-of-the-art social networking technology. (Examples of such collaborative research are not uncommon in the US, like the HHMI initiative, University of St. Thomas, Minnesota, and are largely recommended by all recent review reports like the *Bio 2010* by NRC).

This scheme offers the means to empower teachers of colleges who are the mainstay of the undergraduate science in India; they are, currently, a demoralised set of individuals, largely isolated from the mainstream practice of scientific research and more importantly, from the active research-network. As undergraduate teachers and students are made part of the process of creation of knowledge though a collaborative approach, this program envisages that in the near future, the practice in the classroom truly reflects what goes on in scientific laboratories and the research field, in general. The idea is to offer avenues and possibilities to alter the scenario by bringing about a change in the nature of ties and relations of an incipient network of institutions and individuals.

Networking such a large number of colleges/universities and research institutes, as India has, may look formidable, though if one can develop approximately 500 hubs (about one each in a district), these will act to facilitate the process and thus networking such a large number of teachers and researchers will become feasible.

2 Author: Luke O'Connor (http://pagmo.sourceforge.net)

Each hub needs to cater to and work on a reasonably smaller number of nodes (e.g. about 40 colleges, in this case). It will become sustainable once these links are activated through collaborative research projects. "No node in such a network is meaningful on its own right, but only by virtue of the links the node has with the neighboring nodes." (Nagarjuna & Kharatmal, 2011). Further, it does not escape us that this functional network, by natural extension will involve not only the sprawling education system but can eventually promote Citizen Science Programs, too.

The network model in action: The CUBE Summer 2012 Initiative

We give below one such narrative; a working model that offers a plausible alternative that according to us, will bring about a paradigm shift in Science Education in India:

The Collaborative Undergraduate Biology Education (CUBE) Summer 2012 is a pilot study for Collaborative Undergraduate Biology (CUB) Research initiative to create a network of research and resource centres, throughout the country, catering to undergraduate biology research. These centres are essentially college laboratories that are expected to act as resources for bringing in undergraduate colleges in India under the tenet of inquiry science, process-approach towards science, discovery learning and collaborative research. We present here a phase-wise description of this ongoing CUBE program:

Phase I: The first phase was a 5 week hands-on research program during the summer vacation started in an academic institution on April 23, 2012 with three participating colleges situated in a metropolitan city of India. The program continued in the institution campus till May 30, 2012. A total of 19 students participated in the program and had either appeared for their first year, second year, third year of the 3 year bachelor's or the second year Masters examinations in the area of biological sciences.

Phase II: The next phase of the CUBE continues further by the 3 colleges networking with their neighborhood colleges to establish an undergraduate research, starting with the continuous maintenance of the Simple Model Systems[3] developed in Phase I. Thus each participant college in phase I not only establishes an undergraduate biology research lab using the simple model systems that they worked with in the CUBE summer 2012 program but also conducts workshops for 4 neighborhood colleges each, for helping them establish similar labs in these colleges. The functionality of this newly established link is ensured by the research projects that each college from phase I will carry out with the neighboring colleges. Thus what we expect to have at the end of October 2012 is a functional network of [1 (academic institute for CUBE Summer 2012) + 3 (phase I colleges) + 12 (neighborhood colleges)] 16 colleges from one of the metropolitan cities + another 4 colleges[4] (each from other major cities in India); a total of 20 undergraduate college hubs.

Phase III: In the subsequent phase, each of the 20 colleges from phase II will network 5 more colleges each; again by first helping them to establish simple model systems based biology research and further collaborating with them on research projects. Thus, with a multiplicity factor of 5 at level III, we expect to form a functional network of around 100 undergraduate colleges in India by the Summer of 2013.

Phase IV: A similar cascade effect even with a multiplicity factor of as low as 2, is expected to network around 200 colleges by October 2013.

Phase V: A network of around 400 colleges (multiplicity factor of 2) is expected by Summer 2014.

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3 A detail narrative of the CUB Research (Phase-I) using Simple Model Systems Approach is available in digital format at http://beta.metastudio.org/gstudio/resources/documents/show/1318/ as a supplementary file and a summary scheme of the same is depicted as FIgure 2 on the subsequent page.

4 The colleges networked by means of workshops like CURE (Collaborative Undergraduate Research & Education) initiative. For details of the CURE initiative, see www.metastudio.org.

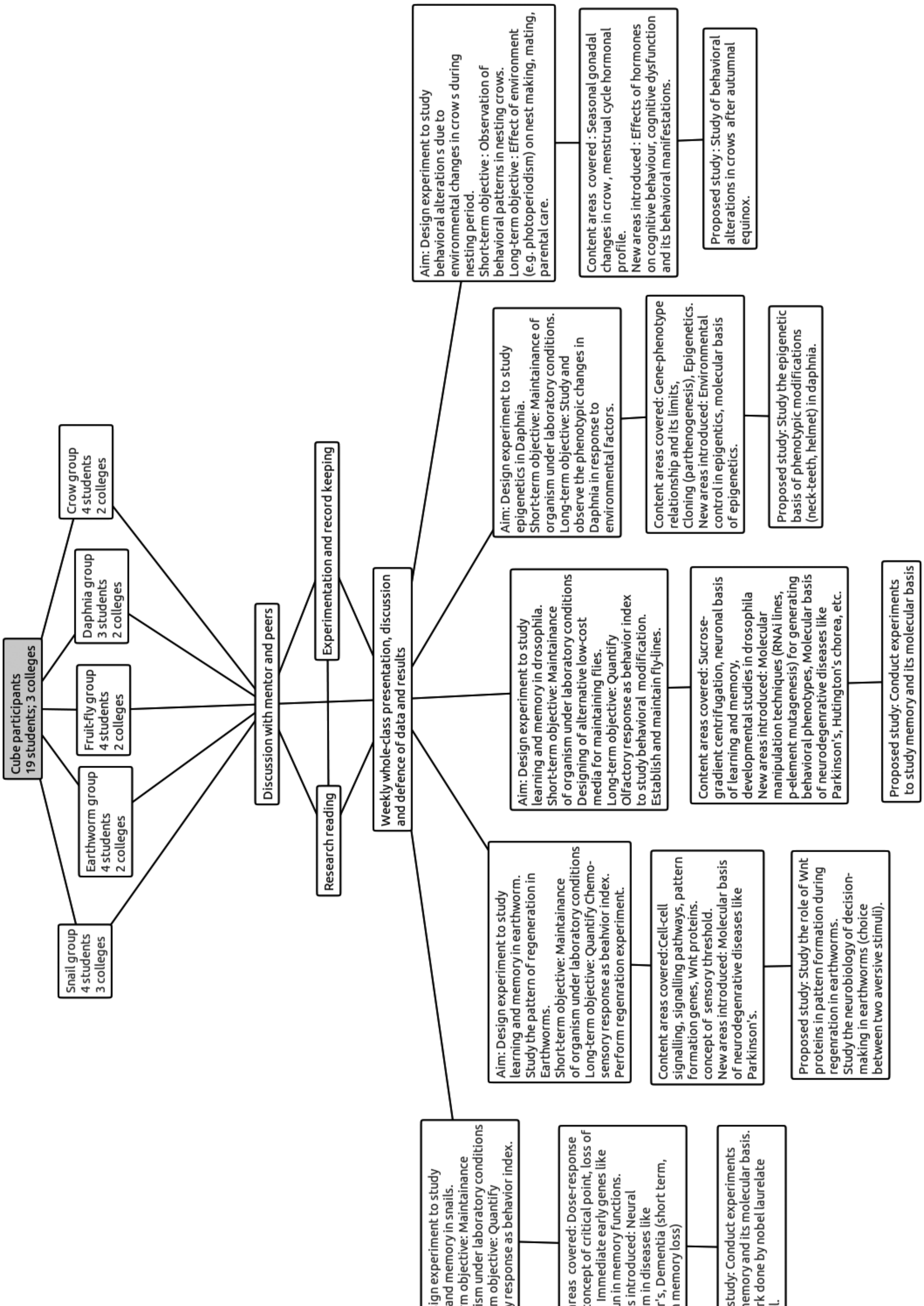

Figure 2: Summary scheme of the CUBE summer 2012 programme using Simple Model System Based Research

Discussion and Conclusions

In the following section we present a glimpse of who has benefited from the CUBE program, in what ways and how that provides an impetus to the cascade phenomena that has already started showing its effect by means of students setting up undergraduate research program in their respective colleges. We had in our mind certain expected themes of the outcomes at the start of the project and the discussion is centered around those themes:

a. What does it mean to be a graduate?

The spirit of 'graduateness', a term defined in the higher education policy documents of the United Kingdom, is the state of preparedness of the student to appreciate the extent of their subject, that is the student should not only know the background of the subject but should also possess the skills to appraise and interpret new information or discoveries. This will give them a sense of ownership of the subject and the comfort and confidence to make a transition from being a passive observer to becoming an active participant (Entwistle et al., 2002, MCcune & Hounsell, 2005).

There is a great deal of scaffolding that is required to smoothen the entry of students from high school science to college science. The shift in focus from gaining experiences about the already known world to a world full of possibilities is not at all an easy one. If the students are not convinced early enough of the possibilities and challenges of research in college science then fewer numbers will feel the necessity to undertake science as a career option (Brewer & Smith, 2011).

Some student responses to a free-wheeling questionnaire at the end of the CUBE summer 2012 program justify the claim:

> "The CUBE summer program has changed my objective and motivation and my way of thinking and questioning on any subject. Before joining the CUBE programme I never questioned my subject (i.e. why am I doing this? what is my interest in it?). These things have now started coming in my mind and it has made me more motivated for my subject."

> ".....I had no idea of what real biology is. I was just doing biology for the sake of scoring marks."

> ".....what I have acquired through the discussions about science is, my attitude towards science has been changed. It has motivated me to go deep into any concepts that I never thought."

b. What tangible outcomes has the CUBE been able to provide?

Skill development is inevitable in the course of any engagement with research project. Thus whether or not these skills have been deliberately sought, any student completing a research project will have acquired a valuable set of life-enhancing experiences.

When the students were asked to contrast the CUBE laboratory sessions with the regular college practicals, the students expressed that the CUBE projects giving them a lot of scope to discuss possible variations to an experiment and try it multiple times. They regarded this interesting because it gave them the real sense of experimentation and the importance of multiple trials for establishing the reliability of the results. They wrote that such a practice gave them confidence in their data.

c. Is a programme like CUBE accessible to all students and colleges?

The concept of research and research labs is one that invests a lot in the laboratory equipments and materials but we have, by the use of very simple model systems, proved that what is required is the sophistication in the mind of the researcher rather than the sophistication in instruments for engaging in good research. This is particularly important to establish in a developing country like India where most of the colleges would hesitate to even try out such practices because of the limit on capital involvement in conducting research.

Some student responses have been very interesting in this regard:

> "....before coming to this programme, we had a notion that complex biology research requires a lot of sophisticated machines, techniques, etc. We never thought that simple organisms could give insight into very deep research areas. After this programme, we have realised that research doesn't necessarily require fancy equipments and that relevant questions can do the trick."

> "After joining the CUBE programme I came to know that research can be done by anyone by using some sophisticated ideas and some good observation."

> "I use to think that research means having a very big lab, doing reactions and having very hi-fi stuff, but I have learned that many complex things can be studied using simple systems."

d. What does the CUBE offer students who do not want to pursue sciences at higher studies?

We content that a minimum scientific literacy (akin to the concept of *biological literacy*) is not only desirable but also essential for becoming an autonomous and informed individual of the society. There is certainly a value in having experienced the knowledge about science; the how's and why's of science. An understanding of the methods of scientific inquiry, the relationship between claimed knowledge and presented data, an appreciation of the culture of science and of the close interactions between science and society are important for making informed decisions in everyday lives.

e. Were the students having fun and enjoying it?

Having a sense of ownership of the learning process, being motivated for it and deriving fun out of such learning represents a radical shift that takes place in the learning style for most students during their involvement in a research project. The project belongs to them and they are the active performers in its progress. This sort of personalised learning converts enthusiasm into productivity which in turn feeds into their feeling of self-worth. Many students find this independence empowering and motivating. They respond positively to the acquired responsibility for their own learning. These valuable aspects of a research experience contribute to the student’s personal, professional and scientific maturity (Luck, 2009).

A general increase in the feeling of competence and self-worth can be seen in the student responses to the differences between the CUBE research programme and the college laboratory courses.

> “....the feeling of self-worth is more as we put in our ideas and experiment them in contrast to college practicals where we do the same work as others and everybody follows the lab manual.”

> “....we are asked to come up with our own ideas and it makes us feel worth.”

> “There is no pressure for correct answers and we make mistakes and find right answers.”

> “....confidence in explaining the work done to others has increased a lot as the experiments and concepts were developed by us through discussions.”

f. Do teachers need to be active researchers?

There has been a lot of debate on the link between teaching and research in higher education in recent years (Sears & Wood, 2005, Jenkins et al., 2007). Engaging (developing, guiding) in undergraduate research projects can be a straightforward way of integrating teaching and research. Moreover, if student research projects are viewed as part of one’s teaching, it can help reduce the burden of the course considerably.

Student research differs from other kind of research in its purpose: it is part of learning, the emphasis is on process rather than outcome. So in spite of the uncertainty of the outcome of the project *per se,* any research project can be considered as a success if the student emerges from it with an understanding of what science is and how it works. (Petrella & Jung, 2008).

These changing ways of learning call upon a revision in the traditional methods of assessment and evaluation to incorporate student's scientific thinking through open-ended problem-solving abilities. Further, students working in collaboration will start to understand how research is a collaborative effort and will develop teamwork skills. They will also help each other to achieve greater breadth and depth of understanding.

Results from the Phase I CUBE initiative are already visible. We will discuss them in brief here: Each of the three participating colleges have already established research labs in their colleges, using simple model system-based approach. One of the colleges (suburban) has already established a network with two more neighboring college and is helping them to establish their own lab with simple model systems. Participants from phase I have also initiated the process of entering into collaboration, with other interested participants from different colleges, on various research projects. These research projects will be supervised by the teacher-mentors of respective colleges. More short-term workshops to introduce CUB research in undergraduate colleges are in the pipeline at three centers in a metropolitan city and three other major cities of India.

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From Relational Reasoning to Generalisation through Tasks on Number Sentences

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The current literature on algebra education calls for considering early algebra as a preparation for algebra teaching and learning. In this paper, we use tasks on number sentences as a context to explore the development of algebraic thinking in Grade 6 and 7 students. We discuss strategies used by students to solve these tasks and justifications or explanations given to support their responses. The findings of the study suggest that students move from purely computational strategies to relational reasoning and later generalised thinking. The use of box as a representation for number sentences supported students' thinking about structures and the movement from relational to generalised understanding. The study offers an instance of how early algebraic thinking in students in a classroom environment can be guided by students' thinking, conflict generation, and learning by consensual meanings.

Introduction

Algebra is one of the most difficult topic areas in elementary school mathematics, with the use of letters for unknown numbers and variables presenting a major hurdle to students. The shift from working with numbers to working with letter symbols requires well designed instruction that facilitates the transition (Banerjee, 2008). There are other identified challenges in learning of algebra such as understanding of equality, making generalisations, operating with letters, and flexibly dealing with procepts. Here we report a study which investigates students' thinking and learning of early algebra using number sentence tasks.

In a typical mathematics curriculum in India, children are first exposed to algebra in Grade 6. Algebra begins with discussion on the arithmetic properties (like closure, commutativity, associativity, and distributive property, identity) with the use of variables. The idea of variable is strengthened through pattern generalisation which leads to forming and solving simple linear equations. In Grade 7, solving algebraic equations becomes a major theme. Methods of solving linear equations (trial and error, balancing, and transposing) are followed by framing and solving equations from word problems. In Grade 8 students enter the world of quadratic equations and polynomials. The emphasis is on doing algebra or using algebraic notation. However, developing the tools for thinking algebraically is a perspective that does not yet find a place in the typical Indian mathematics curriculum. By algebraic thinking, we mean the act of deliberate generalisation and expression of generality (Lins & Kaput, 2004), analysing relationship between quantities, noticing structure, studying change, generalising, problem solving, modelling, justifying, proving, and predicting (Kieran, 2004).

Algebra research in 1980s and 1990s has focused on formulating stages for algebra learning and identifying student difficulties and its sources (Lins & Kaput, 2004). The later research conceptualises early algebra and explores teaching approaches to try it in classroom with younger children. *Early algebra* means building background contexts for problems to be solved using intuition or previous knowledge (Carraher & Schliemann, 2007), with the objective of exposing students to generalised mode of thinking while they are dealing with arithmetic. The development of relational understanding and focus on structures is central to early algebra. In the context of number sentences, relational (or structural) understanding means students attending to the *structure* of the sentence to decide what numbers make the number sentence true, not to carry out all the calculations indicated in order to determine the values of the missing number (Fuji & Stephens, 2008). Therefore, students who are able to use relational thinking to solve open number sentence problems consider the expressions on both sides of the 'equal to' sign while students with computational thinking view numbers on each side as representing separate calculations (Stephens, 2006 cited in Hunter, 2007). One of the ways in which development of structural thinking can afford processes of abstraction and generalisation (Mulligan, Vale, & Stephens, 2009) is exemplified in this paper.

In this paper, we share insights from our study, intended to explore number sentences (or "*expressions*") as a context to introduce early algebraic ideas to students with a focus on their progress to relational understanding and generalised thinking.

Objectives of the study

The current study is a part of a larger study, which aims to support teachers' knowledge of students' thinking through the design of tasks that support teacher reflection. The phase of the study reported in this paper is the attempt to explore students' algebraic reasoning when exposed to *early algebraic* ideas through contexts like number sentences, pattern generalisation, proof and justification, etc. Based on students’ reasoning, we plan to prepare student cases for discussion among mathematics teachers and teacher educators.

Methodology

The data collected was from a summer camp organised for Grade 6 and 7 students from three English medium schools in the vicinity of HBCSE. 68 students (37 boys and 31 girls) participated in the camp. The students were in the beginning of their academic year. The two groups of students were: 33 students (majorly Grade 6) in morning and 35 students (majorly Grade 7) in the evening batch. The summer camp continued for a period of 9 working days with a two-hour session every day. Two of the authors were the teachers for the camp. Data sources include classroom observations, teacher logs, and students’ written and oral responses. The objectives of teaching were informed by literature on student difficulties and early algebra. Since there were different contexts used on different days of the summer camp, for the purpose of this paper, we elaborate on students' responses to tasks centered around number sentences. We viewed the videos of lessons on number sentences and identified episodes demonstrating the students' changing ways of dealing with number sentences. These episodes were transcribed for the purpose of reporting in the paper. Students’ oral and written responses are analysed in the context of classroom discussion.

Task Design and Implementation

Teaching of algebra depends on how children are introduced to express qualitative relationships focusing on general mathematical relations (Fuji & Stephens, 2001). An important consideration for us in designing tasks for students was that the engagement in tasks should provide some evidence of children's capabilities of reasoning and abstract thinking. We knew that one of the useful routes is working on algebraic expressions through the broadening of arithmetic ideas, which can create more opportunities for student learning (Banerjee, 2008). Since it is the first time that these students are exposed to algebraic thinking (or algebra), we were keen on using number sentences as a beginning context. We were curious to find out the affordances of the number sentences task as students' reasoning progressed. We also used tasks of 'comparing quantities to elicit multiple strategies from students' (Naik, Banerjee & Subramaniam, 2005).

The beginning tasks on number sentences (Table 1) were designed to understand students’ identification of the relations among numbers and make their thinking explicit. As the tasks progressed we observed students' movement from procedural ways to reasoning structurally while solving number sentences, i.e. reasoning based on the relations between the terms in the numerical expressions. This observation guided us to design later tasks in order to give students an opportunity to move from relational thinking to generalised thinking.

Objective	Beginning Tasks on Number Sentences	Later Tasks on Number Sentences
Making students to explicate/ verbalise their (relational) thinking	76 + 47 = ___ + 48 876 + 547 = ___ + 878	876 + 547 = □ + 878 a + b = a – 1 + ___ a + b = a + □ + b – □
	57 – 41 = 56 – ___ 457 – 341 = ____ – 342	457 – 341 = 456 – □ a – b = a – 1 – ___ a – b = a – □ – b + □

Table 1. Tasks used in the four Teaching Sessions

The beginning tasks for completing number sentences were guided by the notion of equality and relations in numbers. We started with examples like 76 + 47 = ___ + 48 and soon shifted to using larger numbers in order to direct students' attention to the structure of number sentences. The initial responses of students to these tasks were largely computational. A majority of the students added the two numbers on the same side of equal to and subtracted the number on the other side from the sum. As the students started identifying and talking about relations in numbers on either side of equal to, they were introduced to the need for expressing any number in the form of relations they identified. The notation of *box* emerged as a placeholder for an unknown number in this process. The reason for using a *box* instead of a letter as an unknown was indications from the research literature that variables are difficult for students to decipher as numbers. The *box* was introduced as a place-holder representing 'a place for any number', or precisely as students said it '*any number can go inside it'*. We found that the box representation gave freedom to students to talk about generalisations and facilitated mathematically rich discussions around the given equations. Apart from filling the missing value in addition and subtraction number sentences, we also had tasks on true/ false sentences and creating sentences individually and in groups.

Data Analysis and Findings

Before presenting the transition in students' thinking from computational to relational to generalised thinking, we would like to describe the classroom culture and pedagogic moves which supported us in knowing about students' thinking and therefore take decisions while teaching in classroom.

Typically, each teaching session began by asking students to respond to a set of problems either in a worksheet or on the chalk board. Students could choose to work either individually, with partners or in groups. After they finished spending some time on the problem, they would explain their method to the whole class, during which other students and teacher posed questions if they were not convinced. After one strategy had been discussed and agreed upon, students who proposed a different strategy came up and explained their strategy. The blackboard was used to record different strategies proposed by students. There was a discussion on the effective strategy and what makes some strategies more effective than others. We noticed the evolution of a classroom culture where students would refer to each others' strategies by citing their names, pose questions when in doubt, or comment on each others' strategy.

Students were introduced to the idea of number sentences and were encouraged to explicate the reasons for the truth of a number sentence. Students' explanations served as a way for teacher(s) to know about their prior knowledge and the connections they make, their approach to problem solving, etc. There were also discussions on the significance of (thinking and) asking why to find the reasons for responses. The accepted 'reasoning' was consensually defined as trying to explicate what we are thinking when we solve a problem and why we think the strategy we choose works.

From Computational to Relational (or Structural) Thinking

In the beginning, almost all students had a computational approach towards addition number sentences. Students carried out the calculations for pair of numbers on one side of the “equal to” sign and taking away the number on the other side to find the number in the blank (Table 2).

S23[1] (using computations)	**S49 (blank as variable)**	**S18 (using variable *x*)**
53 + 38 = 54 + __	**48 + 39 = 40 + ___**	**53 + 38 = 54 + __**
53 91	87 = 40 + ___	53 + 38 = 54 + *x*
+<u>38</u> - <u>54</u>	87 – 40 = ___	53 + 38 – 54 = *x*
91 <u>37</u>	47 = ___	91 – 54 = *x*
		<u>37</u> = *x*

Table 2. Student Responses to Number Sentences (Session 1)

While doing this procedure, all the students were convinced with the rule that '*sign changes when we move from one to the other side of equal to*'. The conversation that follows was carried out with several students in interviews as well as during classroom teaching.

Classroom Excerpt 1: Procedural Understanding

Number sentence: **48 + 39 = 40 + ___**

Student: 48 plus 39 is 87. 40 is subtracted from 87.

1 Students have been named from S1 to S68. Henceforth, this naming is used to refer to individual students.

Teacher: Okay, how?

Student: When it goes to the other side it will be 87 minus 40. So answer is 47.

Teacher: How does the plus becomes minus when it goes to the other side?

Students: It is a rule.

Teacher: But why does it work?

Students: It is a rule only. It is true.

Teacher (to class): Are you all convinced about it?

Students (in chorus): Yes

The proposition of sign change was treated as a given rule. Neither did the students raise a question on why this is true nor did they know the reason. It was difficult to make them think about the need to know why this is true and holds for any equation.

Another approach that exemplified the use of procedures was replacing the blank with a specific letter. Many Grade 7 students substituted the blank with an *x* stating '*let the blank be x'* followed by which they solved the equation to find the value of *x.* They continued to think that any unknown should be replaced by the letter *x* and then all the numbers should be taken on the other side of *x* and computed (S18, Table 2). Students using this procedure had the same idea about sign change as others, using the rule without knowing the reason.

Also, while going through students' work, we found that majority of students did not face the commonly reported difficulties in literature like interpreting 'equal to' as 'something to do signal' or as 'closure of expression'. We think that not making such errors might have been due to the students being older and instruction that they have had.

The computations done by students assured that students got the correct answer but as Fuji & Stephens (2001) suggest, the goal is to focus children's attention on the underlying mathematical structure exemplified by that sentence. Students figured out the uniqueness of number sentences being posed to them in the next session. Classroom Excerpt 2 marked the beginning of looking at relations between numbers in a given set of number sentences.

Classroom Excerpt 2: Towards Relational Understanding

Teacher: There is something similar in all the number sentences, right?

Students: Yes.

Teacher: There is something common, what is it?

Different answers from students:

Students: All of them have plus, dash (blank), some numbers, same way to reach answer

S7: Teacher, in each sum of the three numbers...two numbers are very close

The students were convinced of the similarity stated by S7 and as the discussion went on, another student S2 expressed that 'a*ctually equal to is like a balance. If we take away something from one side we have to give it back. So we take it away from the other side also or add it to the same side*'. This was a crucial juncture and students readily accepted this idea. Despite this discussion, we found many students still using computations to solve number sentences. On probing, we discovered that students felt that computation was a secure way to get a correct answer. However, the new discourse in the classroom was about effective strategies, relation between numbers, equal to as a balance, etc. It was interesting to note that the students using procedural approaches realised that the efficient strategy was to compare numbers on either side of equal to and so their justifications changed in the later sessions. We found that in the second session, a number of students started using both the methods to solve a number problem, where they treated one way to solve and the other to verify their answer.

S36 (relational then procedural)		S4 (procedural then relational)		
79 + 46 = ___ + 48		**62 + 19 = ___ + 20**		
48 – 46 = 2	79 + 46 = 125	62 81		20 – 1 = 19
79 – <u>77</u> = 2	125 – 48 = <u>77</u>	+<u>19</u> - <u>20</u>	or	62 – 1 = <u>61</u>
		81 <u>61</u>		

Table 3. Students' Use of Relations and Computations (Session 2)

The evidence from comparing students' responses from Session 1 and 2 showed that almost all the students used computations to solve number sentences in the first session. But as we moved, we witnessed a change in students' strategies and reasoning from procedural to beginning relational thinking.

Nature of Relational Thinking in Students' Reasoning

Students continued to use their methods (computational and/ or relational) for fill in the blank problems, true/false number sentences, and for creating and solving their own sentences. But we found students using different representations to express relations in numbers. There were explanations with words, using diagrams, using numbers and computations, writing more than one reason, etc. (Table 4). Students stated that these solutions (using relational thinking) made their responses quicker and we found that they were gaining confidence in the use of relations. Often they would also look for similarities in different representations to justify their strategy.

S31	S33	S64
45 + 22 = 23 + 44 +1 -1	**27 + 32 = ___ + 28** 27 + 1 = 28 32 + 1 = 33 Therefore, ___ = 33	**62 + 19 = __ + 20** "Answer is 61. If we subtract a number from one of the numbers and add the same number to the other, answer will be same."

Table 4. Responses on Number sentences (Session 3)

The idea of 'equal to' as a balance was also getting strengthened. There were other related ideas which were emerging. Some students started using the diagrammatic representation of the balance between the two numbers to show commutative property.

=
264 + 191 = 191 + 264 (presented to class by S 49)
=

Students started using this explanation to support other claims for instance: S40 wrote that *'20 = 20 because equal to is a balance and on each side equal weight should be there'*. Also, the discussion on the sign change was revised and students now could make sense of the changing sign with the explanation of balancing. The justification for sign change was extended from number sentences (with the relation between two numbers) to any two expressions on either side of equal to (S64, Table 4).

From Relational to Generalised Thinking

After students attained a level of comfort in working with number sentences, the trajectory took a different turn. A student in the beginning of the fourth session said that '*this (pattern) works for all the numbers... I take any number add one to the first number and subtract one from the second number, I get the same answer*'. At this point, there was a discussion on whether it is possible to express this relation as a generalised mathematical statement. This was accompanied with the introduction of a new representation called *box*. The different levels in which this generalisation happened in class was

Level 1: $a + b = a + 1 + b - 1$

Level 2: $a + b = a + 5 + b - 5$, (5, 6 or 10)

Level 3: $a + b = a + 100 + b - 100$

Level 4: $a + b = a + \square + b - \square = a - \square + b + \square$

The sequence of number sentences made students generalise with the *box* as representing any number. When asked about the conditions under which the above number sentence will be true, students became more specific. The conditions stated by them were '*a and b hold the same value on either side of equal to and the box refers to the same number in a number sentence'*. This was extended to saying that '*the sign of the numbers inside box should also be the same and it can be a fraction, decimal or integer'. The box thus signified the representation for any number.* They extended their understanding of a and b as any whole numbers to them belonging to different classes of numbers. It was interesting to see the enthusiasm with which students pursued the idea of generalisation with *box* as a generalised number and proving that 'the sum of the two numbers remains the same if any number or box is added to the first number and the same is subtracted from the second number' (Level 4).

Thus, it was found that the strategies used by students while justifying number sentences involved complex interweaving of computational-structural understanding, articulation of relational thinking and the movement to generalisation. We saw shifts in students' reasoning from computational thinking to developing relational understanding to the need for generalised statements and their proofs. The later sessions focussed on the ideas of justification and proof of generalised statements.

Conclusions

Achieving generalisation is a cornerstone in learning algebra at the school level. The analysis of students' work on number sentences and the trajectory in their reasoning verified the potential of these tasks as a context to trigger relational reasoning. The trajectory of working on number sentences was seen as starting from procedural (or computational) to relational to generalised thinking, supporting the view that understanding of structures is a key to generalisation (Mulligan et al., 2009). Generalised reasoning reinforced students' idea of equations as a *balance* where they were found demonstrating compensation of quantities symbolically. Along with the role that classroom culture and students' prior knowledge played in development of this trajectory, we also identified how intermediate resources such as use of a box supported the trajectory towards generalised thinking. The use of box provided liberty to students to put anything inside it - small, big or even a negative number. We think that box represents a partial symbolisation of the concept of variable and students found it easier to relate its use both as an unknown and a variable.

Number sentences is a powerful context and can be integrated with the existing Indian curriculum. Students' use of number sentences brings forth the algebraic nature of such arithmetic tasks. However, the movement from computational to generalised thinking in a flexible mode entails a significant role of the teacher, including identifying the appropriate prompts, and planning for the unexpected student responses. Understanding the teacher's role in the trajectory of students' thinking is one of the crucial components of teaching algebra in school.

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Recruiting Minority Students into STEM through Experiences in being a Teacher

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The Academy for Future Teachers (AFT) model has shown promise in preparing and inspiring underrepresented high school students to future science careers. Students were recruited into a 3-week summer program collaboratively taught by K-12 teachers and college professors. Our survey study looked into the nature of their participation in the program and how this participation influenced their a) outlook on teachers, teaching, and learning, b) attitudes in science and mathematics, and c) understanding of science and mathematics content. The AFT experience allowed students to develop greater understanding about science and mathematics teachers, teaching, and learning and the nature of science and mathematics. Results indicate that the AFT program provides students with important experiences that have implications for their future choice of a STEM career.

Introduction

Our study was carried out to examine how a group of African American high school students' participation in a three-week intensive and immersive summer STEM teacher education program called the Academy for Future Teachers (AFT) influenced their *a) outlook on teachers, teaching, and learning, b) attitudes in science and mathematics, and c) understanding of science and mathematics content.* African American students' academic achievement, especially in science and mathematics, lags far behind the White population and most other groups in the United States. This also has a domino effect of having African Americans underrepresented in STEM professions. The reasons for African American students' disengagement and underachievement in science and mathematics are many. Various scholars have also provided recommendations to mitigate these trends. The AFT program, including student experiences, was designed mindfully with knowledge of these recommendations. The underlying focus of the AFT program was to develop a sense of self-efficacy and agency in the students so that they are able to confidently pave an appropriate pathway toward a STEM (or even a non-STEM) career that empowers and enables them to become active, critical, and discerning participants of a democratic society.

Theoretical Framework

The theoretical framework underpinning this work centres upon the idea of identity of individuals from minority populations. Identity has been found to be a key component in programs with goals to recruit future teachers from underrepresented groups (Barton & Tan, 2010). Learning can be seen as knowledge and experiences that are built through social processes and interactions with shared experience that can give people a "sense of self and meaning" (Boaler, William, & Zevenbergen, 2000) that are central to one's identity. Part of the inspiration necessary in recruiting minorities into STEM fields is the importance of focusing upon the role of identity within the individuals. Phinney (2005) contends that ethnic minorities find that having affiliation with an ethnic group identity is essential in providing positive psychological wellness. Additionally, Bandura (2002) believed that individual agency played a role in the cultural and cross-cultural differences in efficacy and knowledge. Ethnic identity is a complex and multifaceted construct which is typically described as an individual's ideas and attitudes pertaining to his or her own ethnic group membership. The multifaceted construct includes ethnic consciousness, subconscious beliefs, ethnic identity formation, ethnic identification, language, and self-esteem. The AFT program provides a way to develop students' identity as they begin to think of themselves as teachers, mathematicians, and scientists.

Methodology

Research Context

In the three-week AFT program, participants in cohorts took part in three unique experiences, each lasting a week. The three unique experiences emphasized mathematics and science content and pedagogy in, i) elementary science and mathematics, ii) secondary and middle school science, and iii) secondary and middle school mathematics. A team of three individuals, comprising of an experienced K-12 schoolteacher, an experienced STEM education faculty member, and a team leader facilitated each of the three experiences. Data was collected within the AFT program; a three-week long intensive and immersive STEM summer teacher education program intended to empower underrepresented minority high school students by providing them necessary experiences to critically examine possible STEM and STEM education career pathways. To this end, the program offered its participants authentic, engaging, and meaningful experiences to develop their understanding of the nature of science and science learning and teaching, nature of mathematics and mathematics learning and teaching, and conceptual understanding in science and mathematics.

AFT Program Participants

To participate in the AFT program, underrepresented minority students from the metro area high schools were invited to apply into the program through information flyers, brochures, and applications kits sent to the schools. In addition to completing the standard application form, students were required to have a minimum GPA of 2.5, submit a brief narrative on why they wanted to be part of the AFT program, and submit two letters of recommendation from their teachers. A total of 52 students were recruited to participate in the program. We excluded participants who were not able to complete both the pre and post surveys. Of the 42 participants taking part in the research, seven were males. In addition, thirty-six participants were African-American, five were Asian, and one was Hispanic. The participants' ages ranged from 15 to 17 years, with most participants being 16 years of age and rising seniors (going into 12th grade) in their school.

Data Collection and Analysis

Students' application forms to the AFT program were used to gather demographic and academic information such as race, gender, age, school, grade level, and GPA. The students also completed a pre/post AFT experience science and mathematics attitudes (SAM) survey. The SAM survey is a four-level forced response 60-item (30 science and 30 mathematics) Likert survey that inquired about students' attitudes, motivations, identity, and future intentions in science and mathematics. In order to gauge students' learning of select science and mathematics concepts after their experience in the AFT program, a pre/post content assessment was also administered.

Results And Discussion

Students' Notions of STEM Teachers, Teaching and Learning

The pre/post SAM survey enabled us to examine any changes in students' ideas about science and mathematics education as a result of the AFT program. In addition the survey also allowed us to understand students' general notions of science and mathematics. There were six items (three in science and three in mathematics) in the SAM survey that related to students' notions about their science and mathematics teachers. These are presented in Table 1 below. The survey was scored using the following convention: strongly agree = 4, agree = 3, disagree = 2, strongly disagree = 1.

Item	**Mean***	**Standard Deviation**
Teachers encourage me to do well in mathematics	3.48	0.505
Teachers encourage me to do well in science	3.24	0.821
Teachers encourage me to take as many courses as I can in mathematics	3.07	0.778
Teachers encourage me to take as many courses as I can in science	3.10	0.821
Teachers think I am the kind of person who could do well in mathematics	3.17	0.696
Teachers think I am the kind of person who could do well in science	3.21	0.645

Table 1. Students' Notions of their STEM Teachers, *n=42

The results indicated that students felt that their teachers largely support their science and mathematics learning and achievement in the schools. Students reported their teachers encourage them to do well in science and mathematics. Teacher encouragement and other adult and peer encouragement is an important factor contributing to students' participation in science and mathematics. The mean scores of 3.24 and 3.48 from a maximum possible score of 4 for science and mathematics encouragement respectively are relatively high. Students acknowledged that there is encouragement from teachers to do well. The survey also revealed that teachers encourage students to take many courses in science and mathematics. As students take more courses in science and mathematics there's greater potential for shift toward more positive attitudes about science and mathematics (Brotman & Moore, 2008). Students also felt that their teachers thought that they could do well in science and mathematics. To the students, what others, especially caregivers including teachers and parents think of them and how they support and encourage them play a key role in their academic motivation and confidence. Keeves (1975) initially formalized the idea that students' academic attitudes and achievement are influenced by attitudes and expectations of parents, teachers, and peers. Research by Hatchell (1998) and others have found students' views of teacher encouragement in science and mathematics to have a strong relationship to students' attitudes and motivations toward these disciplines. Stake's (2006) study also provided strong evidence that social factors such as parents, teachers, and peers play an important role in the development of students' motivation and confidence to achievement in science and mathematics.

In Table 2 below and the paragraph following it we discuss some of the quantitative results that we obtained about students notions of STEM teaching. Five SAM survey items related to students' notions of teaching.

Item	Mean*	Standard Deviation
Teaching mathematics requires good knowledge of the content material	3.60	0.544
Teaching science requires good knowledge of the content material	3.55	0.550
Teaching is an easy career	1.69	0.715
I expect taking advanced courses in mathematics will be helpful to me in teaching	2.95	0.909
I expect taking advanced courses in science will be helpful to me in teaching	2.95	1.011

Table 2. Students' Notions of STEM Teaching, *n=42

Certain student notions of STEM teaching were revealed through the analysis of the SAM survey (Table 2). Students largely acknowledged that teaching science and mathematics required good knowledge of the content material. This also matched with their idea that taking advanced courses in science and mathematics will be helpful in teaching. Darling-Hammond (2009) also emphasizes the importance of teachers having appropriate subject matter knowledge. Numerous studies show that how teachers are prepared and their knowledge of the subject matter has an influence on student achievement even after teacher and student demographic, including socioeconomic, characteristics are controlled (Wayne & Youngs, 2003). Results of the SAM survey also revealed that students did not think teaching was an easy career (mean = 1.69). It is also important to note that prior to the AFT program, students' notion that teaching was an easy career had a mean of 2.14 with a standard deviation of 0.977. T-test revealed (see Table 3) that the difference between the means was significant, suggesting that students' AFT participation enabled them to have better understanding of what it requires to become a science or mathematics teacher and to teach science and mathematics. It should be noted that our threshold for statistical significance was set at $p < 0.05$.

Item	Pre Score	Post Score	Standard Deviation	T-statistic	p-value
Teaching is easy	2.14	1.69	1.041	2.817	0.007

Table 3. T-Statistic for Teaching is an Easy Career, n=42

Using Table 4 below we discuss some of the quantitative results that we obtained for students' notions of science and mathematics learning. Sixteen items, eight in science and eight in mathematics related to students' views of learning. Students in the survey (see Table 4 above) reported that they are confident in doing science and mathematics and they have the ability to do AP (Advanced Placement) science and mathematics courses. In comparing the pre/post SAM survey results, it was found that there was a statistically significant increase (from 3.05 to 3.26; p=0.027) in students' confidence in their ability to do mathematics after their AFT experience (see Table 5). Their confidence is also matched with their self-report that they earn good grades in science and mathematics courses. Students' confidence in science and mathematics is also attuned with their ideas on whether learning science and mathematics required special abilities that only some people possessed. We noticed a statistically significant shift in their ideas about needing special abilities to do science (from 2.40 to 2.10; p=0.026) and mathematics (from 2.43 to 2.07; p=0.009) from pre to post AFT experience (Table 5). In the post SAM survey, students believed less strongly in the notion that one requires special abilities to do science and mathematics. There was also a statistically significant shift in how students perceived the difficulty in learning science after their AFT experience. Prior to AFT experience, students rated 'science is hard for me' 3.00. However, after their AFT experience the mean rating decreased to 2.67. This shift (p=0.029) indicates that students perceived science to be less difficult. It is asserted here that the role of the AFT program to impart confidence and empower students to pursue science and mathematics courses and later STEM careers is significant. Several studies report that students' self-confidence is one of the key factors that determine future success. Based on Bandura's (2002) social cognitive theory which describes how individuals exercise personal agency for career development, Lent, Brown, & Hackett (1994) state that students' career interests, STEM related or otherwise, are based on their self-efficacy beliefs, and these beliefs affect career choice and actions.

Item	**Mean***	**Standard Deviation**
I am sure of myself when I do mathematics	3.26	0.665
I am sure of myself when I do science	3.07	0.808
I think I could do Advanced Placement (AP) mathematics	3.07	1.022
I think I could do Advanced Placement (AP) science	2.98	1.047
I can draw upon a wide variety of math techniques to solve a particular problem	3.05	0.764
I can draw upon a wide variety of scientific techniques to solve a particular problem	2.79	0.750
I get good grades in mathematics	3.14	0.751
I get good grades in science	3.36	0.533
I enjoy being in mathematics class more than any other class in school	2.43	0.914
I enjoy being in science class more than any other class in school	2.55	0.993
Learning mathematics requires special abilities that only some people possess	2.07	0.867
Learning science requires special abilities that only some people possess	2.10	0.850
Mathematics is hard for me	2.81	1.065
Science is hard for me	2.67	1.141
Most subjects I can handle, but I just can't do a good job with mathematics	3.10	0.932
Most subjects I can handle, but I just can't do a good job with science	2.95	0.825

Table 4. Students' Notions of Science and Mathematics Learning, *n=42

Item	Pre Score	Post Score	Standard Deviation	T-statistic	*p*-value
I am sure of myself when I do mathematics	3.05	3.26	0.606	-2.291	0.027
Learning mathematics requires special abilities that only some people possess	2.43	2.07	0.850	2.722	0.009
Learning science requires special abilities that only some people possess	2.40	2.10	0.869	2.308	0.026
Science is hard for me	3.00	2.67	0.954	2.264	0.029

Table 5. T-Statistic for Students' Notions of Learning, n=42

While the survey revealed that the AFT students have relatively high confidence in their ability to do science and mathematics, their enjoyment of science and mathematics courses compared to other courses that they take in school was reported to be average. Research based on data collected from the Program for International Student Assessment (PISA) (OECD, 2007) shows that students' reported enjoyment in science predicted their future science engagement. This also falls in line with Dewey's assertion that activities that are 'playful' and 'serious' are most appropriate for learning. Ainley & Ainley (2010) contend that experiences that "generate enjoyment and focused attention" are important requirements for authentic and impactful learning (p. 5). Ainley & Ainley's idea of 'enjoyment' and 'attention' can also be thought of as enjoyment and engagement. We feel that the terms 'enjoyment' and 'engagement' must be treated differently, in the sense that one can be engaged in doing science while not enjoying the experience.

Students' Attitudes in Science and Mathematics

In order to see if there was a general attitude shift in the way students think about science and mathematics we combined survey items that specifically related to science and mathematics attitudes and calculated an aggregate score for attitude pre and post AFT experience. The maximum possible score that could be obtained in the aggregate was 24. T-test on the pre/post AFT scores revealed that there was a statistically significant change in science attitudes ($p<0.001$), but no statistically significant change in mathematics attitude. Positive notions about science increased from a pre score of 14.26 to 17.26 in the post survey. Positive notions of mathematics changed from a pre score of 17.93 to a post score of 18.24. We suggest that the reason that there was not a significant increase in mathematics attitudes is because of ceiling effect. Students' scores were relatively high for attitudes in mathematics in the pre AFT survey, thus they had little room to increase their already high scores.

Using Table 6 below and the paragraph following it we discuss students' specific attitudes in science and mathematics. Sixteen survey items, eight from science and eight from mathematics, related to student attitudes in science and mathematics. The post SAM survey confirmed our assertion that AFT students' high affinity for science (3.10) and mathematics (3.12). This was somewhat expected as students voluntarily apply into the AFT program. knowing that the program focuses on developing their science and mathematics capacities Students also largely agreed on the inherent and potential value of science and mathematics. Students indicated that knowing science and mathematics is an important life skill necessary for both genders. They also did not believe that gender played a role in science or mathematics achievement or performance. While students indicated that knowing and doing well in science and mathematics will help them earn a living and is important for their future (score >3), they also indicated that they do not see themselves using science or mathematics after high school graduation (score > 3). This dichotomy in the perceived value of science and mathematics and students' assumed future usage of science and mathematics is intriguing to us, and we're continuing to seek rational explanations to this.

Item	Mean*	Standard Deviation
I like mathematics	3.12	0.772
I like science	3.10	0.790
Mathematics is an important life skill	3.52	0.634

Item	Mean*	Standard Deviation
Science is an important life skill	3.33	0.786
Males are naturally better than females in mathematics	1.55	0.670
Males are naturally better than females in science	1.52	0.594
Studying mathematics is just as necessary for women as it is for men	3.57	0.703
Studying science is just as necessary for women as it is for men	3.57	0.703
Knowing mathematics will help me earn a living	3.40	0.665
Knowing science will help me earn a living	3.14	0.843
I see mathematics as something I won't use very often when I get out of high school	3.38	0.731
I see science as something I won't use very often when I get out of high school	3.21	0.750
Doing well in mathematics is important for my future	3.26	0.767
Doing well in science is important for my future	3.24	0.821
Math courses will be very helpful to me no matter what I decide to study in future	3.31	0.780
Science courses will be very helpful to me no matter what I decide to study in future	3.17	0.881

Table 6. Student Attitudes in Science and Mathematics, *n=42

The impact of the AFT program is also evidenced in the pre/post analysis of students' attitudes in science and mathematics (see Table 7 below). Pre AFT program, students largely believed that mathematics was not an important life skill (1.40). However, post AFT survey revealed a relatively drastic (mean difference 2.119) shift in this belief (3.52), which was statistically significant at $p<0.000$. Similarly, students' view that science is important for their future showed a statistically significant shift post AFT experience. Students' high attitude toward science and mathematics, and the shift of certain attitudes to even higher scores post AFT is significant and encouraging. While students' high attitude in science and mathematics are associated with high academic achievement and higher probability of future STEM career, many students often develop negative attitudes toward science and mathematics as they progress through the grades. Several researchers have reported that positive attitude toward science and mathematics is linked to students' personal experience in and their perceptions of the importance of science and mathematics. Students' science and mathematics experiences within the AFT program enabled them to experience science and mathematics at a personal and intimate level, thus allowing for the development increased positive attitudes in science and mathematics.

Item	Pre Score	Post Score	Standard Deviation	T-statistic	*p*-value
Mathematics is an important life skill	1.40	3.52	1.152	-11.922	<0.000
Doing well in science is important for my future	2.88	3.24	0.958	-2.416	0.020

Table 7. T-statistic for Students Attitude in Science and Mathematics, n=42

Students Understanding of Science and Mathematics Content

Since the AFT program required students to teach science and mathematics content to middle grade and elementary students through reform-based practices, the AFT students became engaged in learning science and mathematics content. They also experienced science and mathematics content through authentic and engaging reform-based practices. Analysis of students' pre and post content assessments in science and mathematics revealed that they scored significantly higher ($p<0.002$) in the post assessment. In the science assessment, 89% of students showed improvement from pre to post assessment. Similarly, in mathematics 91% of students showed improvement in their post assessment. We agree with the notion that improvement from pre to post content assessment would be expected and not terribly surprising. However we also note that from our current and past experiences in the schools and through examining preservice and inservice teachers' pre and post assessments of their students, we know that improvement from pre to post assessment in science and mathematics is normally observed in about 55 to 75% of the students. In the AFT program, approximately 90% of the students showed improvement in content. This significant improvement in science and mathematics content knowledge is indicative of high student disciplinary (science and mathematics) engagement within the AFT program.

Conclusion

Strong encouragement from individuals who are familiar to the students is an important factor influencing their engagement is science and can counter pressures from peers who are not supportive of academic success. Encouragement also has the potential to influence students to take more courses in science and mathematics. When this happens, students' attitudes about science and mathematics increasingly become positive and they come to have greater understanding of the epistemology of science and mathematics. They came to know some of the intricacies involved in teaching science and mathematics and the importance of having appropriate content, pedagogical, and pedagogical content knowledge. They came to know these intricacies through their immersive experience in the AFT program, where they participated in various authentic and contextualized encounters with subject matter and pedagogy. Students' participation in the AFT program also allowed them to become more confident about their abilities to do science and mathematics and have better understanding of the nature of science and mathematics.

We assert that the role of the AFT program to build confidence and empower students is significant. We also assert it is equally important that learning experiences be engaging and enjoyable. As a result of the AFT experience students had more positive attitudes about science. The design and the implementation of the AFT program enabled the students to show higher gains in pre/post assessment of content as compared to gains experienced in the schools. Through the AFT experience students developed greater understanding about science and mathematics teachers, teaching, and learning and the nature of science and mathematics in near authentic contexts. These gains in understanding contribute to the development of self-efficacy and agency, resulting in an identity shift that empowers and enables African American students to increase their STEM educational and career aspirations.

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Strand 4

Information and Communication Technologies in STME

Digital Resources in School Science and Mathematics in Regional Language

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Homi Bhabha Centre for Science Education (HBCSE), a constituent unit of the Tata Institute of Fundamental Research (TIFR), Mumbai has launched an ambitious programme to design and test digital resources for schools (OER4S) in science and mathematics. These are web-based resources developed collaboratively by academicians, teachers and enthusiastic parents. They are made available to all the stakeholders (teachers, parents and students) through internet and also through the distributed classrooms set up by the Maharashtra Knowledge Corporation Limited (MKCL). The programme aims at supporting the education system to offer quality school education in Marathi (the language of the state of Maharashtra). The digital resources are being field-tested for their suitability and relevance in the schools run by well organised big educational societies / organisations in two regions of the state of Maharashtra. The philosophy of the programme, the strategy of its implementation, mechanism of obtaining feedback from stakeholders for mid-course corrections etc are described in this paper.

Introduction

Indian education system is full of diversities. There are schools run by local self governments, central government bodies and private organizations in the country. The curriculum followed and the facilities provided in these systems are widely different. In spite of these differences one thing is common in all these schools. They are trying to prepare students to face the school leaving examinations. They are happy if their students fare well in these examinations. Concern for quality education and for developing personality of the child is often missing in Indian education. A variety of reasons like crowded classrooms, poor educational facilities in schools, lack of in-service training programme for teachers etc, are put forth for this pathetic situation. These reasons are genuine and need to be looked into critically. At the same time one needs to pay attention to educational resources that are available to students, teachers and parents associated with Indian school system. A cursory look at these resources brings out the fact that attempts to develop supporting instructional material in regional languages are almost non-existent. For a majority of population the only resource available is the text book written for school children. There is, therefore, an urgent need of development of appropriate educational resources in regional languages that would influence pupil-pupil, teacher-pupil and parent–pupil interaction to bring about quality improvement in school education. Moreover, this material has to be made available through distance mode as the face to face interactions have severe limitations (Sharma, 2005). With this view in mind, Homi Bhabha Centre for Science Education (HBCSE), a constituent unit of the Tata Institute of Fundamental Research (TIFR) has launched a project for development of Open Educational Resources for Schools (OER4S).

The Project

The main objective of the project is to make available resources that can be used to provide quality education to the students studying in Indian schools. The project is being funded by the Rajiv Gandhi Science and Technology Commission of the Government of Maharashtra and is being jointly conducted by HBCSE, Maharashtra Knowledge Corporation Limited (MKCL) and the Indian Consortium for Educational Transformation (I-CONSENT). The project aims at designing suitable material in science and mathematics for all the stakeholders of school education: teachers, students and parents. This material is made available through the website specially designed by MKCL (www.mkcl.org/mahadnyan). Stakeholders are then encouraged to make use of these resources and give feedback. Thus, the project has three phases: Material development, uploading on the website and Field Testing and validation. Each of these aspects are discussed in the following sections.

Material Development

Over the past three decades, HBCSE has developed methods and materials to provide quality education in school Science and Maths. Most of this material has been field tested through field projects undertaken by HBCSE, both, in rural as well as urban areas of the country. Part of the open educational resources for the present project is drawn from the pool of material that HBCSE already has developed in such projects. Apart from HBCSE there are a large number of organizations associated with HBCSE, working for the improvement of school education. Those organizations were persuaded to share their resources. In addition, special resource generation workshops were organized periodically to prepare material taking into account the needs and requirements of students, teachers and parents associated with school education.

Participants for these workshops were chosen from the pool of innovative school teachers, teacher educators, social workers and enthusiastic parents. The participants were oriented in the concept of open educational resources and were asked to prepare material suitable for students, teachers and parents. Material, thus, developed was processed at HBCSE using Unicode package and the printout was sent to the author for editing, modifications and revision. Once the corrections were incorporated, the material was subjected to quality editing. Suggestions received from Quality Assurance Teams were incorporated and the materials were tagged for uploading to the website. The tagging involved classification into two categories: Science and Mathematics. Resources designed for each of these subjects are further categorized taking into account the end users: Students, Teachers and Parents. In addition there is material that is categorised as common material that is useful for all the three stakeholders. Such a classification facilitates both loading of the material to the website and using it.

Uploading Material on the Website

The website of the project is designed and maintained by the Maharashtra Knowledge Corporation Limited. Before publishing the material on the website it was necessary to upload it on a specially designed software package called CDIT (Content Development and Integration Tool). For convenience of use, this material is put on the website as 1. Material for Students, 2. Material for Teachers and 3. Material for Parents.

Material for Students

Material in this section is designed to support learning of concepts in school science and mathematics. As stated above it is conveniently categorised into primary, upper primary and secondary stages. At each level central concepts are identified and a folder is created for it. Within each folder, there are subfolders created for each sub-concept. There are in all 38 folders for Science and 46 folders for Mathematics. Titles of the folders along with subfolders are given in Appendix. In general, it is attempted to provide content related matter to facilitate concept formation and self assessment of the school students.

Material for Teachers

HBCSE has been conducting in-service training courses for practising science and mathematics teachers for the last three decades. Through these courses it could gain insights into the needs and requirements of teachers teaching these subjects in different set ups. Based on these insights following types of material is developed for teachers.

1. Conceptual Discussion that consists of Concept Maps, Lesson Plan and Explanatory Notes.
2. Teaching Aids which include PowerPoint Presentations, Models / Charts / Posters / guidelines etc. for using them as teaching aids.
3. Activity / Experiment / Project comprising concept-based experiments, activities involving games / skits / puzzles and relevant projects.
4. Pedagogic Guidelines focusing on Learning Difficulties, Recent Developments in school education and guidance for Classroom Management.
5. Research and Innovations, providing survey of recent researches, innovative practices in school Science and Mathematics teaching and action research projects completed by school teachers.
6. Assessing students' learning encompassing Diagnostic testing, Cognitive and affective assessment and Outcome based assessment

Material for Parents

Since a large number of parents in India take great interest in the education of their children, the material is planned according to their requirements. It is essentially of six types:

1. Everyday science and mathematics: It has articles and information on how science and mathematics are influencing our day to day life.

2. Issues related to health and hygiene: This section attempts to highlight the importance of individual health, social as well as community health. A lot of inputs to maintain them are also provided.
3. Parenthood in 21st century: This century has witnessed a large number of changes in parent -child interaction. Generally parents are found confused about the social demands, likes and dislikes of the child and their personality development. Inputs to tackle this situation are offered through this section.
4. New ideas in teaching and learning: Teaching of science and mathematics has witnessed considerable changes in the last few decades. It has led to new ideas in teaching, concept formation and assessment. These ideas are presented for the benefit of parents.
5. Out of school activities to support school education: Students are greatly influence by the activities planned by their parents. Many of these activities can be used to support school education like a visit to Zoo or to museum. Some of such useful activities are suggested along with concrete examples of how to use them effectively.
6. Identification and nurturance of talent: Identification and nurturance of talent is a challenging task for many parents. In the absence of such understanding, the child is forced to take up the studies that might not suit to his aptitude and interests. Suggestions are offered to avoid such wastage of talent.

Common Material

The material common to all the three stakeholders is designed taking into account the needs and requirements of students, teachers and parents. It includes the following types of material:

1. Biographies: life histories of 120 scientists and mathematicians who have contributed to the growth of these disciplines.
2. Question-answers: More than 550 questions raised mainly by school children are included in this folder. Answers to these questions are prepared taking into account there linguistic and social background.
3. Published articles: Different articles (253) related to school science and mathematics is published in daily newspapers and magazines. Some of these articles are chosen and uploaded with the permission of the author.
4. Published books: A variety of books are also published regularly that has relevance to school science and mathematics education. Some of the relevant books (45) are also uploaded with the permission of the publishers.
5. Open forum: This forum is planned to achieve a free dialogue between teachers, teacher educators, researchers, students and parents. Teachers, parents and researchers have so much to share with each others. Open Forum (OF) provides them a platform for getting doubts clarified and for sharing ideas / experiences. In addition, OF attempts to inform various stakeholders about conferences, seminars, workshops, contests, etc. related to school education. There are various schemes to recognize the work of intelligent students, innovative teachers and creative researchers. The Forum makes available relevant information about them.

Field Testing

An attempt is made to field test the digital material put on the website. In order to facilitate the use of digital material by students, teachers as well as by parents the website is made easily accessible to these stakeholders through the network of distributed classrooms managed by MKCL. Two big educational societies, conducting hundreds of schools in the state of Maharashtra are identified for field work. Workshops are arranged both at HBCSE and in the field to create digital literacy among the teachers of these organizations. They are then encouraged to make use of the material available on the website and provide us feedback related to their experiences, its relevance and utility. Based on the feedback received from the stakeholders appropriate modifications are being made in the material. In addition, for giving feedback the stakeholders are also appealed to contribute creatively to the development of new and relevant material.

Opportunities and Challenges

E-learning as stated by Zemsky and Massey (2005) has a tremendous potential. The present web based programmes offer ample opportunities to cater to the needs of students, practising teachers and parents. Since the material is prepared in regional language (mother tongue), a larger number of these stakeholders can access and use it. Once this programme is validated, the material can be translated to other regional languages. This effort would hopefully bring in qualitative changes in the classroom interaction in rural as well as in urban schools.

In spite of great potential the project poses many challenges. Firstly, the teachers and parents may not be psychologically prepared to receive inputs offered through digital mode. Developing appropriate computer literacy among the stakeholders is, therefore, a big challenge. Yet another challenge is to develop appropriate material to be put on the website. A lot of useful material exists in print form that needs to be converted into digital form so that it can be directly used by teachers, as well as, by parents.

Summary and Implications

The project described in this paper is a model of collaborative developmental work in school education. Three different organizations namely a HBCSE (a research institution), MKCL (a corporate company) and I-CONSENT (a voluntary agency) have joined hands to work for a common cause of improving school science and mathematics education. The experience of past five years has shown that such collaboration can work. One more important aspect of the project is to bring people together for knowledge creation. The material put on the website has been prepared by practising teachers, enthusiastic parents and voluntary works. The project thus was a model of co-creation and collaboration among different stakeholders of school education. It has created a network of about 1500 persons associated with this project.

National Knowledge Commission (2007) set up by the Government of India clearly brings out the importance of open access to information and Global Open educational Resources. The work reported in this paper is in tune with the recommendations of the commission, especially open access nature. It must however be noted that the work envisaged in this project is of gigantic nature. It needs the cooperation of people in developing content, pedagogy, technology as well as in assessment strategies. It is basically a collaborative activity on the lines of Wikipedia: a free encyclopaedia. It will bear fruits only if people with different expertise come together to develop, test and modify the material. The process is expected to be an ongoing activity where the developmental work continues for ever. We are trying to seek the help of different organizations and personnel for this activity. The project is still going on and the work done so far has given positive feedback. Teaching community has welcomed the idea of OER material. At the same time there are encouraging responses from students and parents also. It is hoped that this work will take a shape of a movement soon and will make available field-tested useful OERs for Indian school system. India shares common educational problems with many developing countries. It is, therefore, hoped that the open educational resources developed and strategies and systems generated in this project will have a global relevance to bring about qualitative improvement in teaching and learning of science and mathematics all over.

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Building an Understanding of How to Support Students as they Problem-Solve Within a Spatial Urban Planning Simulation

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Recent modifications to environmental science educational standards in the United States are calling for a perspective that highlights how social and natural systems interact. Students must acquire experience with generating solutions to ambiguous problems arising from the interaction of social and natural systems. Understanding this interaction poses various challenges for the students since they are not trained to solve such problems involving spatial reasoning. To understand these challenges faced by students and recommend scaffolds, this paper presents a case study examining how students make sense of a stormwater management model – a complex human-natural systems model. We highlight how the affordances of the model may have shaped their strategies.

Introduction

Science and technology influence every aspect of our lives today. Students begin to understand these influences in school as they try to make sense of the human-built world. One way of helping students with this task is to frame the problem with a complex systems perspective (College Board, 2009). Complex systems can be represented using simulations that are dynamic and are formed by the interaction of multiple elements organized across different levels of scale. Models showing how local interactions build up to system wide effects are one way of representing complex systems simulations, and have been used successfully to teach complex systems thinking (Wilensky & Resnick, 1999; Goldstone, 2006). In particular, complex systems based models help students understand principles like "emergence" of a system behavior (e.g. individual ant actions giving rise to an ant colony behavior) (Jacobson & Wilensky, 2006; Hmelo-Silver, Marathe, & Liu, 2007). In human-natural systems, an example of emergence would be how human decisions on land cover impact and are impacted by surface and ground water levels. Complex systems based models have the potential to facilitate learning about the science and policy issues arising from such human-environment interactions by letting learners manipulate a model to examine the effect of different land cover patterns (Slattery et al., 2012). However, further research is needed to determine if this approach is effective.

Our exploration of these issues engages students in Green Infrastructure (GI) planning, an authentic problem-based context incorporating Urban Planning (UP) and Environmental Science (ES) disciplines. GI is defined as "an interconnected network of green spaces that conserves natural ecosystem values and functions and provides associated benefits to human populations" (Schilling & Logan, 2008). Since communities do not have infinite resources, they must make strategic decisions about where such green spaces will make the most impact. With the help of disciplinary experts from both UP and ES, we have adapted a complex systems based model from urban planning – *L-GrID* (Zellner et al., *in review*) to give students an opportunity to practice making these decisions. Due to our context, this study includes a key concept of urban planning – investigation of spatial reasoning. In this study, students engage with spatial reasoning that involves (a) identifying various elements (e.g. land cover, drainage points, and elevation gradient) that influence the outcomes of strategic decisions about GI placement; (b) understanding how these elements interrelate and influence each other; and (c) understanding the policy implications of modifying these elements.

Spatial thinking in the social sciences generally demands a simultaneous integration of multiple spatial concepts. This requires students to detect changes in spaces, identify and document changing patterns, study spatiotemporal flows between regions, and measure spatial associations to test hypotheses, among other skills (Janelle and Goodchild, 2011). In UP and ES contexts, this spatial thinking must also be balanced with consideration of competing reward structures. An instance of a context at the intersection of UP and ES is stormwater (flood) management. Effective stormwater management is defined by balancing competing reward functions, such as social priorities (e.g., cost) and natural priorities (e.g., flooding). The value placed on such competing reward structures is influenced by a stakeholder's perspective. Experts in UP believe that such judgments are qualitative and non-objective and often take the form of "reasoned guesses" (Dasgupta et al., 2010). Thus, practice with making such qualitative judgments is critical for the planning process. Ideally training should begin as early as possible so that more time can be spent practicing spatial thinking in the context of competing reward structures and making "reasoned guesses" in real-life scenarios (Zellner & Campbell, 2011). However, there has been a lack of focus in STEM curricula on training students in this essential skill. This often renders recent STEM graduates paralyzed when confronted with decision-making roles dealing with real-world ambiguity. We wish to understand how students make sense of such ambiguous problem scenarios and how we can begin to support this authentic practice within a structured curriculum over extended time. In this paper we present a case study of how one group of students developed their solution strategies while using our complex system based model.

Activity and Study Design

The students' activity environment consisted of a simulated urban area featuring streets (vertical and horizontal lines), city blocks (areas bounded by the streets) and sewers (dark circles on the streets).

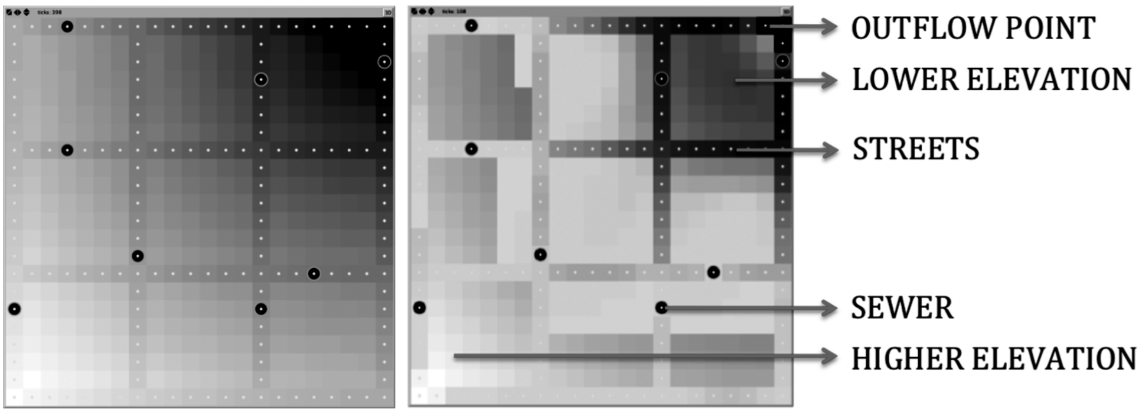


Figure 1. Map without gardens before rainfall (left) and after rainfall (right). Top right region indicates flooding in the lower elevation area after rainfall.

The simulation shows the effects of a "hundred year storm" on the mapped area, illustrating how the arrangement of gardens in the environment leads to more or less effective stormwater management. The maps used in the experiment consist of different elements – (a) two types of land cover: impermeable (e.g., roads, buildings), and highly permeable (swales), (b) sewers (which drain water from the surface but prevent groundwater infiltration), (c) an elevation gradient, and (d) an outflow point at the lowest point of the map (from which water leaves the map). The complex system based model displayed the *two reward functions*: amount of infiltration (amount of water absorbed by semi-permeable and highly permeable land patches) and garden cost ("$10,000" each), respectively representing natural and social concerns. Users could move and place gardens (represented by small square pieces of rigid paper) on land patches, run the simulation, and witness how their garden arrangement influenced the reward functions. Placing gardens on the land would increase the amount of water absorbed, but would also increase the cost of gardens. Thus the task was to minimize garden cost while maximizing water infiltration. Since this was an exploratory lab-based study without real world consequences, we encouraged participants to take the problem-solving task seriously by giving a cash award proportional to their optimization of these two functions. To encourage them to explore the problem space, the final monetary award was based on the best score they were able to attain by optimizing the two functions within their allotted time.

Twenty-two triads of undergraduate students were recruited for this study. Each group tested different arrangements with the model for twelve minutes; a limit intended to mimic real-life planning constraints. Prior work (Slattery et al., 2012) suggests that twelve minutes is sufficient to help the participants get familiar with the problem space and try out multiple solutions. We videotaped and transcribed every group's conversations. This paper presents a microgenetic analysis of one of these groups. This group was selected for the case study because it represents a typical group of participants in terms of solution space explored, cost and infiltration scores achieved. The participants in this group are identified as S1, S2 and S3.

Data Analysis

We analyzed the group conversations using a grounded theory approach (Corbin & Strauss, 2007). We developed a preliminary set of codes based on a small set of conversations and applied it to the entire conversation after verification and refinement across multiple coders. Here, we highlight the justifications provided by students to support their ideas about garden placement ("Justification"), the spatial properties considered in these justifications ("Primary Focus"), and the role played by group members in that conversation ("Role/Buy-in"). One of our units of analysis was 'trials' – sets of conversations that lead to a specific garden arrangement. We also analyzed the unit of 'ideas' – suggested garden arrangements that might or might not have been executed by the group. The ideas and accompanying justifications for taking up or leaving an idea were rich data sources for understanding students' problem-solving strategies during the session.

Findings

In this section, we discuss how students S1, S2 and S3 applied spatial complex systems reasoning to balance the two reward functions – water infiltration and garden cost. Figure 2 illustrates this process and highlights that participants used two strategies for placing gardens: (a) relative to each other and (b) relative to the map features.

Balancing the reward functions

Figure 2 illustrates the group's attempt to balance the two reward functions and highlights the different elements of the complex system based model simulation that they considered while deciding their garden placement. This includes streets or *edges* of streets, *sewers*, *elevation*, *outflow point, amount of rainfall*, amount of *water infiltration*, cost of each garden or *garden cost*, *total score* informed by garden cost and water infiltration, *absorption limit* or the maximum amount of water that can be absorbed by a garden, *water drainage* or path taken by the water to drain out through the outflow point, and *drainage time* or time taken by water to drain out of the map.

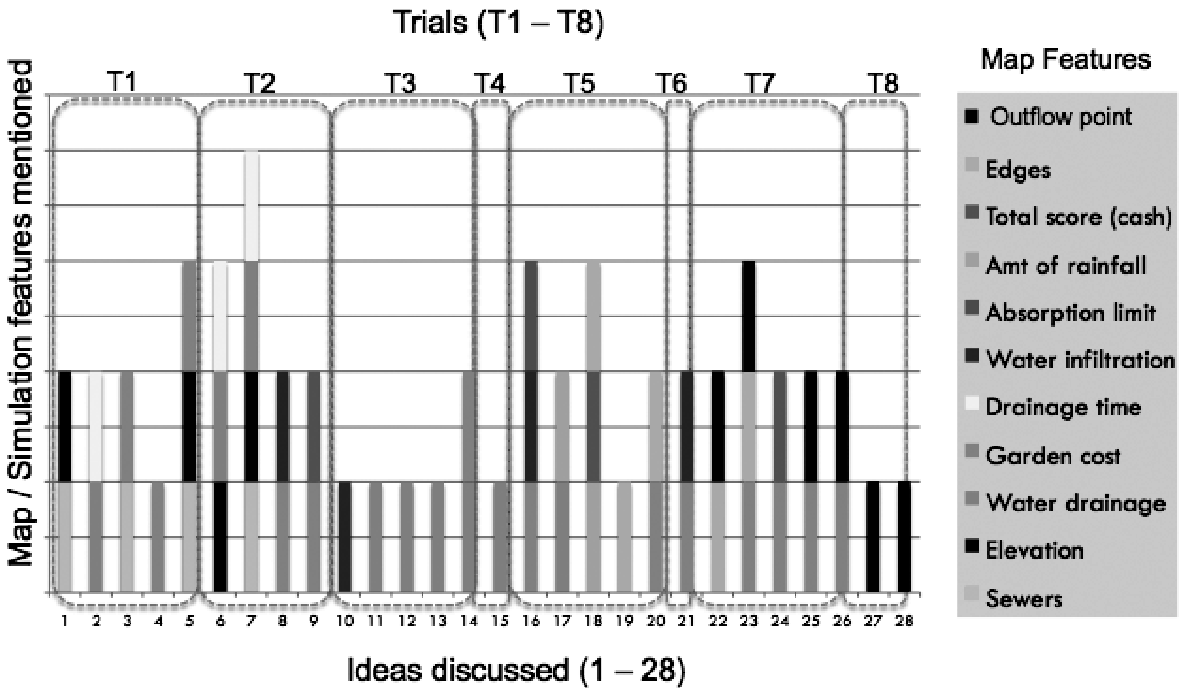
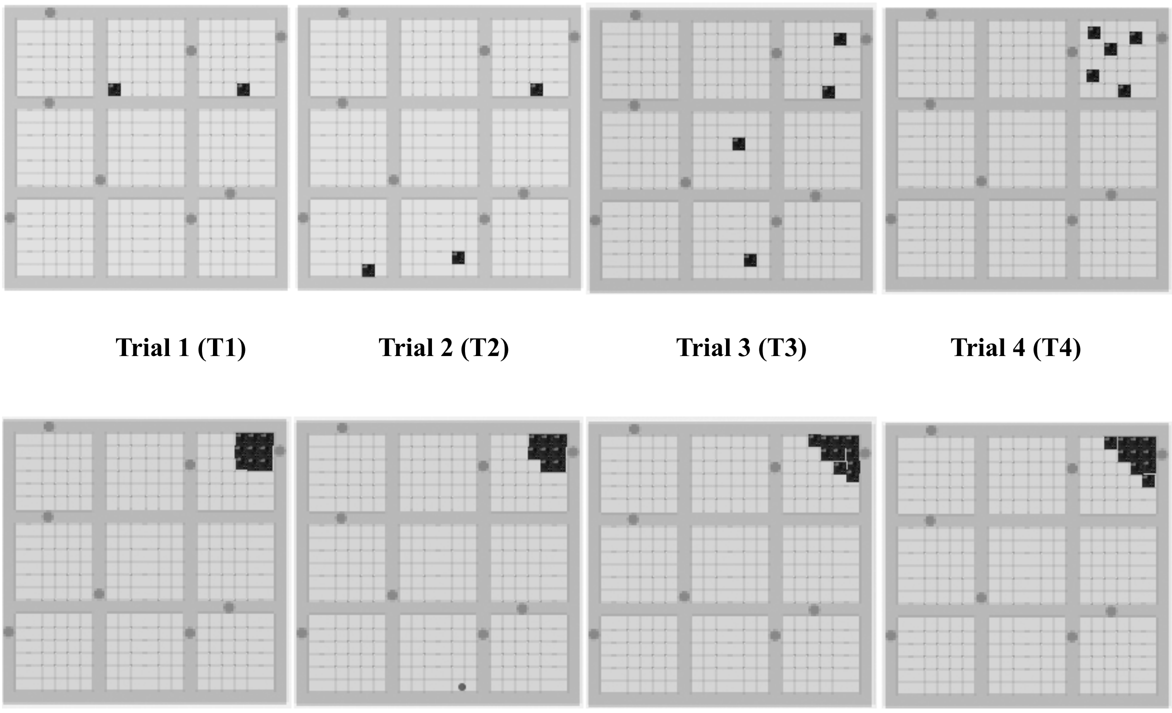


Figure 2. Map elements discussed by the group



Trial 1 (T1) **Trial 2 (T2)** **Trial 3 (T3)** **Trial 4 (T4)**

Trial 5 (T5) **Trial 6 (T6)** **Trial 7 (T7)** **Trial 8 (T8)**

Figure 3. Map screenshots of garden arrangements corresponding to each trial

The graph in Figure 2 helps us understand how ideas were consolidated into consensus solutions, i.e., the final garden placement at the end of each trial shown in Figure 3. The stacked up bars depict that multiple features were referenced within the same idea. For example, in Idea 1, there are two stacked up bars because the group referred to *Sewers* as well as the *Elevation* while deciding their garden placement strategy at this stage.

In Trials 1 and 2 (Figure 2), the group decided to place gardens away from the *Sewers*. Simultaneously, the group also considered *Water drainage* and *Drainage time*. It suggests that they were focused on quickly removing water from the map. It is likely that since sewers were already removing water from the map, they decided to place gardens in areas that did not have sewers to speed up the process of water drainage. However, they noticed after Trial 2 that placing gardens away from the *Sewers* and reducing the *Drainage time* was not improving their *Total score.* This possibly led them to abandon this focus after Trial 2. The group realized that placing more gardens was increasing their *Garden Cost* and thus they tried to maximize the water absorbed with the help of minimum number of gardens. This suggests that the group tried to balance the competing functions of *Garden cost* and *Water infiltration.*

Ideas discussed between Trials 3 and 5 show that the group retained their focus on amount of *Water drainage* and also paid attention to the amount of *Water infiltration*. They placed gardens along the drainage path in order to absorb more water. S1 noted that although the group was trying to minimize the *Garden cost*, they were "not doing enough in terms of absorbing the water (*Water infiltration*) effectively". This direct reference to the two reward functions and a call to pay adequate attention to both the functions indicates that the group was attempting to balance these reward structures. However, frequent mention of *Garden cost* shows that the group maintained their primary focus on the number of gardens.

From Trial 5 onwards, the group's ideas consisted of placing gardens along the *Edges* of the city blocks. They reasoned that since there was a lot of rainwater on the streets in the top right corner, they should place gardens there to absorb more water (i.e. focus on *Water infiltration*). In addition, they focused on the *Outflow point* since most of the water accumulated there. The group concentrated the gardens in this region (i.e. the lower elevation region) and spread out their gardens along the edges of a block to make a triangle (Figure 3) to maximize *Water infiltration*. As mentioned before, the heavy focus on *Garden cost* made them add very few gardens during this time. The group attempted to absorb as much water as possible with the minimal number of gardens, further suggesting that they were trying to find a balance between the two reward structures.

Spatial complex systems reasoning: Placing gardens relative to each other

The group started solving the task with very few gardens that were placed far from each other, indicating an over-dispersed strategy. They continued with this strategy through Trial 3 (Figure 3). After Trial 3, S2 observed that adding gardens to the top right corner was improving their scores. So in Ideas 14 and 15, in Table 1, she suggested adding more gardens in the top right corner. For Trial 4, they moved their gardens to the top right corner of the map and added one more garden in that area.

Idea#	Ideas	Justification	Primary Focus	Role/Buy-in
14	Put all gardens in the top right corner	All the water ends up there	Direction of drainage, garden cost	S2 proposes, S1 disagrees, S3 supports S1
TRIAL 3				
15	Add more in that area	Noticed in simulation that all water ends 'up there'	Direction of drainage	S2 proposes, S1 agrees, S3 agrees (S2 is persistent)
TRIAL 4				

Table 1. Ideas 14 and 15

This was an important learning moment for the group because after Trial 3, they seem to have learned that clumping the gardens together was improving their scores more than the over-dispersed strategy. Beginning with Trial 4 (Figure 3), the placements of the gardens indicate that the group had abandoned the over-dispersed strategy.

Spatial complex systems reasoning: Placing gardens relative to the map features

The second strategy for placing gardens on the map was based on the map elements. Here we will highlight how the group decided where they wanted to clump the gardens (a desirable strategy as shown above). Table 2 shows that in Trial 1, the group started by placing gardens in the top right corner of the map (i.e. near the outflow) because it was the "deepest" region. They reasoned that they had a better chance of absorbing water near the outflow because the water "would definitely get there." However, S2 recommended placing gardens near the middle of the map in order to intercept the water earlier and thus save on the drainage time. Finally, S3 suggested a compromise and they placed gardens near the outflow but in the proximity of the middle of the map.

Idea#	Ideas	Justification	Primary Focus	Role/Buy-in
1	Place gardens in top right corner of the map.	Not many present in that region; It has a low elevation	Sewers, Elevation	S1 proposes, S3 agrees, S2 does not respond
2	Place gardens in the middle block	Catch the water earlier	(Intercept) water flow	S2 proposes without agreeing or disagreeing with S1's previous proposal.
TRIAL 1				

Table 2. Ideas 1 and 2

However, after watching the simulation, the group decided to shift their strategy and placed gardens "higher up" (in the bottom left corner with a higher elevation) as S2 had suggested in Idea 2. The group wanted to reduce the drainage time. They felt that their scores would improve if they were able to capture the water while it was still in the higher elevation. So for Trial 2, the group moved one of their existing gardens from the low elevation (top right corner) to the high elevation area (bottom left corner) and also added an extra garden in that corner. They left one garden in the low elevation area, reasoning that the lone garden there would help absorb the water that was not absorbed by the two gardens in the high elevation area. After watching the simulation for Trial 2, they noted that their strategy of placing gardens in the high elevation area was not improving the total score. Thus, Trial 3 in Figure 3 illustrates the group's decision to place gardens along the path of the water in the middle of the map. Trial 4 to Trial 7 also indicate the group's increasing preference in placing gardens near the outflow (lowest elevation area in the top right corner) as the scores indicated progressively better solutions. Figure 2 highlights references to the outflow towards the end.

Between Trials 2 and 3, the group seems to have learned that placing gardens in the low elevation area near the outflow was more beneficial to them as it improved their total scores. This approach became a core part of their future strategies for Trial 4 to Trial 8. However, Figure 2 shows that beginning with Trial 3, the group also stopped discussing elevation as a justification for placing gardens in the low elevation area near the outflow. It appears that since the group now shared the understanding that focusing on the low elevation would help them achieve the best possible solution for the given problem, they did not feel the need to use elevation as a justification for placing gardens. Instead they began referencing to the outflow point as illustrated by Trials 7 and 8 in Figure 2.

Discussion and Conclusion

This analysis illustrates the process by which students made qualitative judgements about balancing competing reward functions and engaged with spatial thinking. It highlights how and when the group came to prioritize different rewards or strategies for getting rewards. We found that the group's garden placement strategy was influenced heavily by the presence of excess water, probably leading them to clump gardens in the lower elevation area near the outflow. They were also conservative in terms of total number of gardens, seemingly constrained by garden cost. In this discussion, we will explore how these strategies may have arisen, and possible linkages to the simulation design itself.

The excessive concern for garden cost might have been influenced by the time it takes for the numbers corresponding to each reward function to be delivered to the participants. The garden cost is displayed to the participants instantly. However, the group must wait for water to drain out of the map completely before they can see the water-infiltration reward value. This mimics the complexity of a real life environmental planning problem. For example, covering a barren land with trees would cost a lot of money upfront, while benefits are uncertain, occur gradually and are not easily noticeable. Our finding that participants focused more on garden cost (a short-term reward) highlights the endemic problem faced by planners when planning for long-term goals. Further investigation is required to understand how we can alter our intervention to help students develop the skill of balancing short- and long-term benefits. The solution may not lie in altering the simulation itself, however. Delaying the simulation's display of the garden cost to be coincident with the display of the water drainage score would be a way to *test* if the staggered delivery is inducing short-term/long-term reasoning, but it would not help prepare students for encountering these tradeoffs in real life. Ultimately, we may need to develop a curriculum to train students to explicitly focus on short-term versus long-term tradeoffs.

The sub-strategy of placing gardens in low elevation areas may also be rooted in the simulation design. Towards the end of the session we found that the participants switched from a generalized technical vocabulary to a visual vocabulary to refer to spatial features (e.g. substituting "dark regions" for "low elevation" areas). Prior research by Goldstone and Son (2005) recommends the technique of "concreteness fading" in simulations as a way of helping students gain knowledge that is less tied to specific instructional contexts and hence is more transferable. Concreteness fading involves altering the simulation to move from using concrete and definite graphical elements to more generalized, abstract representational elements over time, as a way of getting students to appreciate the key functional features of the simulation. We see evidence of the *opposite* process happening here, however, where the students' conversation is becoming more rooted in the concrete graphical details of the simulation ("dark regions").

Ideally, we would wish student conversation to increasingly involve the key underlying abstract concepts (e.g., elevation), and their implications (e.g., rate of surface water flow). Instead, we found that the group stopped discussing "elevation" after Trial 3 (Figure 2), even though they continued to focus on the lower-elevation region (evidenced by garden placements in Figure 3). This suggests that the students might be overly relying on the simulation's visual features (the "dark regions") as a simplistic cue to guide their actions rather than understanding the role elevation plays in groundwater infiltration. In other words, it seems that they are attending to emergent effects, not the dynamics that produce the effects.

The occurrence of this preferential attention to the final outcome over dynamics, even though the purpose of presenting students with a complex system based model is to help them attend to the system dynamics, presents a design challenge. This suggests that in future work we would present students with a simulation that, rather than depicting a series of final states (e.g., the current water level at each location), depicts a series of *changes* in states (e.g., the increase or decrease in water level at each location).

The results presented here are predicated on a microgenetic study of only one group, and so may or may not be representative of what most students do when confronted with the complex system based model. In our continuing analysis with other groups who participated in the study, we will look to confirm whether the majority of participants were paying more attention to the dynamic features of the simulation (e.g. drainage) or were only looking at outcomes, and whether the majority of groups exhibited a preference for short-term benefits (i.e., prioritizing the cost reward score). If these behaviors are common, we will explore the possible solutions proposed in this paper.

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Learning Science at a Distance: National Open University of Nigeria Students' Perception of Practical Work in Learning Sciences

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The influence of practical work in the understanding of scientific concepts has been receiving attention of many scholars all over the world. In particular, the need to address the little or no consideration of practical work in science teaching/learning process in distance education seems to have received greater attention presently. This paper focuses on students' perception of practical work in learning science through distance education. Data were collected from 450 science students of National Open University of Nigeria using questionnaire as research instrument and descriptive survey design. The research questions raised were answered using frequency counts and percentages. The results indicate that students placed a high value on practical work in the learning of sciences in distance education. Students were also of the opinion that it is essential for science course to include practical work even though the course materials are delivered in a distance mode of education. Further, investigation on this issue may help instructional designers and science curriculum developers to design and incorporate practical activities into science courses in distance education, as it has been done in some developed countries.

Introducation

Providing quality education to millions has been one of the struggles facing developing countries such as Nigeria. However, inadequate access to education may result in many people not participating meaningfully in national development. Hence the need arises for open and distance learning to act as succour for the affected Nigerians, irrespective of tribe or ethnic background.

According to UNESCO (2002), open and distance learning represents approaches that focus on opening access to education and training provision, freeing learners from the constraints of time and place and offering flexible learning opportunities to individuals and groups of learners. The practice of ODL in Nigeria takes various forms, which include correspondence study education, distance learning (Sandwich programmes), Part-Time Teacher Training Programme (PTTP), adult literacy education programmes and Open University.

The National Open University of Nigeria (NOUN) was originally founded on 22nd July in the year 1983 as the launch pad for open and distance education in Nigeria. The government debarred the university on the 25th of April 1984. The university was launched again on 12th April 2001, due to its significant role in the education system of Nigeria (Creed, 2001). The National Open University of Nigeria is also the biggest tertiary institution of the country in terms of the number of students with about 60,000 students as at 2002 (Daniel, 2005). NOUN is the first fully fledged university that operates in an exclusively open and distance learning (ODL) mode of education. Currently, it has twenty three study centers, which are stratified into the six geopolitical Zones of the nation.

The National Open University of Nigeria is devoted towards training professionals in a range of areas through the method of distance learning. The choices of qualifications provided by the university are Certificates, Diplomas, Post Graduate Diplomas and Degrees and the university currently offers 50 programs and 750 courses including sciences.

Considering the nature of science, students studying science courses are expected to engage in first-hand experiences such as observation, measurement, testing hypothesis, or experiment, particularly in higher education (Kirschner, 1991). This can be a serious challenge, for distance education institutions when offering science courses because of the fewer occasions for students to be on campus where laboratory facilities, relevant equipment, and teaching staff are provided (Kennepohl & Last, 2000; Jason &Namin, 2006).

Much debate has been going on, however, as to the role, value or effectiveness of practical work not only in distance teaching settings but also in education in general (Watson, 2002). According to Jason &Namin (2006), the advantages of providing distance students with practical work include; reinforcing student's motivation towards subject matter, generating within students positive attitude towards overall learning and intensifying interpersonal relationships with tutors and peer students.

> Practical work means any teaching and learning activity which involves at some point the students in observing or manipulating real objects and materials. The term "practical work" is used in preference to 'laboratory work' because observation or manipulation of objects could take place in a school laboratory or in and out of school setting, such as the student's home or in the field e.g. when studying aspects of Biology or Earth science (Irwin, 1995).

Moreover, because of the nature of the discipline, science often involves students in first-hand experiences such as observation, measurement or experiment, particularly in tertiary level education. It can present a challenge, however, for distance education institutions when offering science courses because of the fewer occasions for students to be on campus where laboratory facilities, relevant equipment and teaching staff are provided. Apart from basic academic reasons, ensuring that student engage in practical work becomes critical when it comes to the issue of credit transfer between educational institutions as it can fairly represent the credibility to science courses (Osborne, 1993). For example, while you can study a history lesson completely online, you cannot perform nursing clinical online. Thus, physical classroom attendance is mandatory for the completion of some degree programs and this is why practical exercise is necessary due to what they contribute to the learning process.

However, not much research studies have been carried out to investigate the kind of effect brought about by a specific method of practical work on distance student learning. Instead, relevant literature on science courses involving distance education method is rather illustrative. For example, Kennepohl et.al. (2000) review chemistry courses offered at Athabasca University (AU). The study aimed at providing students with integral, accessible, and transferable chemistry courses, the AU chemistry course puts a strong emphasis on laboratory work, using mixed approaches through campus-based laboratories, regional laboratories, and home-study laboratories. Applications of technologies such as video, CD-ROM, internet, and computer-mediated instruction have been also considered in the institution, but the authors make it clear that simulated experiments would not replace hands-on laboratory work. Rather, they believe that technical aids can be better in preparing students for real experience with laboratory work (p.194). Hence, the present study investigates National Open University science students' perception of practical work in learning science.

Statement of the Problem

The important of practical work in learning sciences cannot be over emphasized; it involves development of knowledge skills attitudes for the benefits and growth of individuals and the society at large. The present study sought to investigate National Open University science students' perception of practical work in learning science.

Research Questions

In order to be able to effectively investigate the main problem as stated above, the following research questions are drawn for investigation.

What are the perceptions of National Open University of Nigeria Students of practical work in learning sciences?

Does learning science via distance learning more difficult than the case of face-to-face class?

Is it more challenging to learn science via distance education than the case of other subjects related to social sciences or humanities?

Is it essential for a science course to include practical work even though the course materials are delivered in a distance mode of education?

Can practical work be replaced by computer simulations or other virtual components that do not require a face-to-face class?

Method

Research Design

The research work is a descriptive study on the Students' Perception of Practical work of learning science in Open University of Nigeria. The researcher adopted the survey design because the independent variables are not manipulated.

Sample and Sampling Techniques

The target populations consist of all science students in National Open University of Nigeria. 450 science students were randomly selected from study centers in the south-western geopolitical zone of the country to form the sample for the study.

Research Instrument

The instrument used in the study was a Likert type questionnaire adapted from Josan & Namin (2006). The questionnaire was divided into two sections: section A sought for personal information of the respondents (study center, sex and course of study). Section B was made up of 20 statements on the importance of practical work in learning science. The students were to indicate the extent of their agreement or disagreement with each statementon a 4-piont Lekert Scale. The instrument was validated by three experts in science education and final draft was prepared with reliability coefficient of 0.67 using Cronbach alpha.

Data Collection and Analysis

The data were collected through the administration of the questionnaire to the targeted students by the researcher and collected back immediately.

Data Analysis

Data collected were analysed using frequency counts and percentages.

Results

Research Question One: What are the perceptions of National Open University of Nigeria students of practical work in learning sciences?

S/N	Items	YES	%	NO	%
1	Looking at the nature of science, I think it will be more challenging to learn science without any practical work.	354	78.7	96	21.3
2	I think practical work will help me learn how to use experimental tools.	414	92.0	36	8.0
3	I think practical work will allows me to have a sort of interaction with teacher or tutor to clarify some concepts out well understood.	439	97.6	11	2.4
4	Practical work helps students to develop the understanding of science.	387	86.0	63	14.0
5	Will student gain better understanding of science topic by doing practical work.	369	82.0	31	18.0
6	Practical work should be given an important role in encouraging students to study (science) at higher levels.	385	85.6	65	14.0
7	Science is a practical subjects	439	97.6	11	2.4
8	School science laboratory are a vital part of students' learning experience in science.	360	80.0	90	20.0
9	Laboratory work provides little of real educational values.	144	32.0	306	68.0
10	Practical work promotes the engagement and interest of students'.	342	76.0	106	24.0
11	Practical work develops an ability to co-operate among learners.	370	82.2	80	17.8
12	Practical work develops a critical thinking in learner.	337	74.9	113	25.1
13	Students' find practical work relatively useful and enjoyable as compared with other science teaching and learning activities.	369	82.0	81	18.0

Table 1. The perception of NOUN students of practical work in learning sciences.

Table 1 above shows the responses on students' perception of practical work in learning sciences in National Open University of Nigeria. The population of students who have positive of perceptions of practical work in learning science is higher than the students who thought of the negative opinion to practical work in an Open University.

Reference was made to Table 2 in answering research questions 2, 3, 4, and 5.

Research Question	R	F	%	Cum. %
2. Does learning science via distance learning is more difficult than the case of face-to-face?	Yes	354	78.7	78.7
	No	96	21.3	100
3. Is it more challenging to learn science via distance education than the case of other subjects related to social sciences or humanities?	Yes	360	80	80
	No	90	20	100
4. Is it essential for a science course to include practical work even though the course materials are delivered in a distance mode of education?	Yes	421	93.6	93.6
	No	29	6.4	100
5. Can practical work be replaced by computer simulations or other virtual components could replace practical work?	Yes	155	34.4	34.4
	No	295	65.6	100

R: Response and F: Frequency

Table 2. Responses on Students' view on learning science in NOUN

Discussion of findings

Examining the students' perception, their responses on the nature of science and roles of practical work in science learning , the study shows that 78.7% (see table 1) of the respondents were of the opinion that it will be more challenging to learn science without any practical work. In support of this finding Millar (2004, 2010), sees practical work as an essential component of science teaching and learning, both for the aim of developing student' scientific knowledge and that of developing students' knowledge about science. The study also reveals that 92% of the students believed that practical work will help them learn how to use experimental tools. This is corroborated by Millar (2010) who opine that learning is not discovery or construction of something new and unknown; rather it is making what others already know your own. The results presented on all other statement on this issue in table 1 indicate that students agreed to all the roles of practical work in learning science.

Furthermore, in table 2, it was revealed that 78.7% of the students thought that learning science via distance learning more difficult than the case of face-to-face class. 70.7% also agreed that it is more challenging to learn science via distance education than the case of other subjects. Almost all the students (93.6%) were of the view that it is essential for a science course to include practical work even though the course materials are delivered in a distance mode of education. However, 65.6% thought that practical work could not be replaced by computer simulations or other virtual components that did not require a face-to-face class. These findings conform to that of Jason Chan and Namin (2006) in a similar study carried out in the Open University of Hong Kong.

Conclusion

It can be concluded that the importance of practical work in science is widely accepted by students even in distance education and it is acknowledged that practical work can promotes the engagement and interest of students as well as developing a range of skills, science knowledge and conceptual understanding. Despite the fact that their learning take at distance the students still believed that it will be more challenging learning science in distance mode without making provision to engage in hands-on and minds-on activities. Research also suggests that students design better investigations when they actually carry them out than when only asked to write a plan (Apu, 1988). Based on the findings of this study, it is therefore recommended that Government should make provision for practical work in science courses offer in distance education in Nigeria to allow students to be exposed to practical work involve in science learning. The curriculum developers should also incorporate laboratory activities and practical work in to the curriculum of Open and Distance Learning in Nigeria to enable students to gain necessary experience and skills that will make them compete adequately with their counterparts from convectional universities in the world of work.

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Problem Solving Strategies Used by Pre-Service Teachers in Learning Technology

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Using technology in the classroom to augment the learning of the students is becoming a professional responsibility of teachers in today's technology infused world. Teachers have to constantly learn new software. Learning new software is akin to solving an ill-structured problem and it requires the use various problem solving skills used either in tandem or individually. The present study is an interpretive qualitative study of eight pre-service teachers, narrowed down from 99 pre-service teachers who participated in this study. The study discusses the problem solving processes used by these pre-service teachers while learning how to use Hot Potatoes™ to create an Online Question Bank in their discipline. Implications of working in such a technology enabled problem solving environment are also discussed.

Introduction

Teachers at all levels are expected to use technology (i.e. computers) as it is considered to enhance the teaching learning process in the classroom (for example: Christmann and Badgett, 2000; Waxman, Connell, and Gray, 2002 ; Blok, Oostdam, Otter, and Overmaat, 2002). There are many problems to using technology (discussed in Butler and Sellbom, 2002) but one major issue is not being able to keep pace with the changing pace of technology and being able to learn software on their own. This problem of learning new software is a challenge to many and needs to be addressed because if the quality of education in India needs to improve, assistance from technology is a necessity. One way to address this issue is to present a learning environment to teachers where in the process of learning a new software that has many uses in education, they are able to develop certain skills that can help them experiment and learn more software for their classroom teaching in the future. One such skill is that of *problem solving.*

Problem solving is the process of constructing and applying mental representations of problems to finding solutions to those problems that are encountered in nearly every context (Jonassen and Woei, 2012). Jonassen (2012) clarifies that problems that we encounter in our lives – both in the formal educational system and in the informal arena of life - occurs somewhere in the continuum between a well-structured problem and an ill-structured problem.

Research Context

Learning new software is akin to solving an ill-structured problem. Simon (1978) defines ill-structured problems as those that (a) are more complex and have less definite criteria for determining when the problem has been solved, (b) do not provide all the information necessary to solve the problem, and (c) have no "legal move generator" for finding all the possibilities at each step. Just like, an ill structured problem learning new software provides the learner with opportunities to explore features that she finds useful, interesting and learnable. As the learner learns the new software, she is able to understand the relevance of the new software into her own contexts and gain familiarity with the working environment of the software. In order to learn the various features of the software, the learner could use either a well delineated path as given in the tutorials or could follow a self created mechanism that is helpful to complete the task in hand.

In this present study, Pre-service teachers were asked to *use Masher Program in Hot Potatoes™ to develop your own Question Bank with all types of Questions* possible using Hot Potatoes™ Modules. Hot Potatoes™ (freely downloadable from- www.hotpot.uvic.ca) are a set of authoring tools for creating interactive exercises for the World Wide Web; this authoring tool can be used by anyone with basic computer skills. No prior knowledge of HTML is required and the tool creates an exercise in two formats – one the HotPotatoes format (that can be used for editing the exercises) and the .html format that can be used for viewing the exercises and doing the exercises in a Web browser.

The Hot Potatoes™ authoring tool comes in six modules: **JBC** creates multiple-choice quiz; **JQuiz** that allows text-entry quiz and lets the learner type in words, phrases or even sentences (open-ended); **JMix** creates jumbled-word exercise and this makes the learner arrange jumbled words into phrases or sentences; **JCross** creates crosswords; **JCloze** creates fill-in-the-blank exercise where the learners are expected to enter the words that are missing; **JMatch** creates matching exercise, and the learner is expected to match items in the 1st column with those in the 2nd either using a drop-down menu or by using a drag and drop option. The Windows version of this tool also has a module known as **the Masher**. The Masher is a tool for automatically compiling batches of Hot Potatoes™ exercises into units. The Masher links the various exercises created using above mentioned modules, together using the navigation buttons, and create an index file for the unit. All the six modules along with the Masher program have a uniform screen appearance of icons, menus and lay-out, but the steps of creating the exercises in different formats vary in them.

As a scaffold for the pre-service teachers, two video based modules were created and given to the pre-service teachers. These modules used the Cognitive Apprenticeship Model as the theoretical construct in their conceptualization and design. Cognitive apprenticeship (Collins et al., 1991) is a well-recognized instructional approach with extensive roots in the instructional design literature (Brown, Collins, & Duguid, 1989; Ceci, Rosenblum, & De Bruyn, 1998; Quinn, 1994, 1995; Tripp, 1994) that is prescribed for designing learning environments. The cognitive apprenticeship framework specifies four dimensions for designing powerful environments, namely: content, method, sequence, and sociology. Gopal (2011) discusses how video based material developed using Cognitive Apprenticeship Framework augments Pre-service teachers' technology skills in directly using, applying and learning technology.

During this study, the pre-service teachers were engaged in learning Hot Potatoes™ and developing their Question Bank. This allowed them to use various problem solving approaches. The questions of interest for this research were:

i. What problem solving processes did the pre-service teachers use while learning how to use Hot Potatoes™ to create an Online Question Bank in their discipline?
ii. What was the quality of the question banks created by the pre-service teachers using Hot Potatoes™?

Methodology

Sample

The sample in the experiment consisted of 99 (94 Females and 5 Males) Pre-service teachers from Army Institute of Education, Delhi Cantt- a teacher education institute for the dependants of Indian Army personnel. The pre-service teachers are admitted into the Institute based on their performance in an Entrance Examination. This was the first time in the history of the Institute that such a skewed sex ratio was observed. These 99 pre-service teachers are expected to choose two teaching methodology subjects from the following options of Integrated Sciences, English, Hindi, Mathematics, Sanskrit, Social Sciences, Economics, Business Studies and Accountancy- based on their educational qualification. In this batch maximum number of students had the subject combination of Integrated Sciences and English, followed by Social Science and English followed by Integrated Science and Mathematics. An important point to note is that Hot Potatoes™ does not have provisions for Hindi font, the Hindi methodology students had to choose perforce their second methodological option – Social Science or English.

Tools for Data Collection

Question Bank Evaluation Rubric- Scoring rubrics are descriptive scoring schemes that are developed by teachers and other evaluators to guide the analysis of the products or processes of students' efforts (Brookhart, 1999). This rubric was used to evaluate the Question Bank that was developed by the Pre-service teacher. The rubric evaluated the following seven parameters – Planning of the Question Bank, Research into the Questions, Levels of Questions, Authenticity of Content, Grammar and Language, Utilization of Features like Timer, Images, Hints and Configuration, Seamless integration of Technology and Pedagogical Principles in the Question Bank.

Reflective Journals: All pre-service teachers maintained a reflective journal where they recorded their day's progress, the problems they faced, how did they overcome the problems and their experience in the lab. Loughran (2002) argues that reflection emerges as a suggested way of helping educators better understand what they know and do in developing their knowledge of practice through reconsidering what they learn in practice. Reflective Journals offers a place for teachers to explore the planning and outcomes of curricular, instructional, relational and other classroom activities (Cole & Knowles, 2000). To help the pre-service teachers document their experience in the lab, questions like -What did you plan to do? What sequence did you follow – did you directly experiment with the software or did you view the tutorials – any specific reason for choosing this option? What discussion did you have with your peers today about the lab work? – were given as guided questions to help in their documentation process.

Procedure of Data Collection

Before the commencement of the study, the Pre-service teachers had already completed 6 months of training in the Institute. They had also completed their *teaching internship program for 20 weeks @ 3 days per week*. This program ran parallel to the college curriculum and the pre-service teachers were expected to deliver a minimum of 20 lesson plans in their respective methodologies and also conceptualize, conduct and analyze a test based on the lessons taught by them in their respective methodologies and allotted classes.

They were then instructed to develop a question bank on the class and topic of their choice. This topic should have been something they would have taught during their teaching-internship program. This question bank was prepared on the paper and was to be used a starting point during the study.

The study took place over six days, where all the students came in groups of 20 into the laboratory. Each group was given 90 minutes per day to work on their project. The lab was equipped with internet connection (so that the pre-service teachers don't access the tutorials etc from the publisher's website without the knowledge of the pre-service teachers the sites were blocked and help files deleted from the program). At the end of the six day period it was expected that the students learn how to use Hot Potatoes™ and create the question bank in their topic of choice. It was not binding on them to use the same questions that they had initially planned for the question bank, they had the freedom to change the questions – both in content and level- to maximise assessment process using computers. No instruction on this accord was given to the pre-service teachers. The duration of 6 days @ 90 minutes was chosen based on the ease learning the software and the experience of the researcher- where pre-service teachers were seen creating question banks within 5 days @ 60 minutes in the lab. In order to give an advantage to the pre-service teachers who were using the computer for the first time, the time duration was increased and the Masher program was included in the task. Figure 1 represents the parameters involved in the study.

All the 99 Pre-service teachers created Question Banks and these Question Banks were analysed using the rubrics mentioned above. These scores were then arranged in an ascending order – according to their subject disciplines of Integrated Science, Social Science, English and Mathematics. Based on these scores two groups were created, **Group A** consisted of the Adept Hot Potatoes™ Users based on the high score on the rubric and **Group B**, constituted those students who had lower score on the rubric due to either poor quality questions, questions not integrating computers in assessment purposes, incorrect questions, incorrect question type, and non-functioning of the question bank in the web-browser. The middle scores were left as such. *The reflective journals of* ***top four and bottom four scorers*** *were chosen for analysis in this study.*

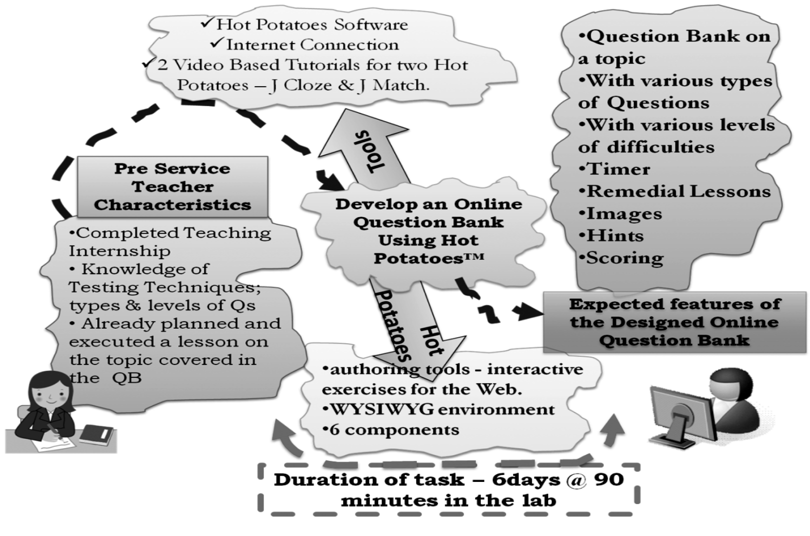

Figure 1: Schematic Representation of the Study

Discussion

The research was an *interpretive qualitative study*. An interpretive approach provides a deep insight into "the complex world of lived experience from the point of view of those who live it" (Schwandt, 1994) and assumes that reality is socially constructed and the researcher becomes the vehicle by which this reality is revealed (Cavana, Delahaye, & Sekaran, 2001). The researcher used a *process approach towards* the research to study the problem solving processes used by the pre-service teachers while learning how to use Hot Potatoes™ to create an Online Question Bank in their discipline.

A problem solving strategy or process is a technique that may not guarantee solution, but serves as a guide in the problem solving process (Mayer, 1983). The reflective journals analysed show evidence of the following **types of problem solving processes commonly used by pre-service teachers**:

- **Trial and Error** -where the pre-service teacher worked on numerous alternative solutions before zeroing down on the best possible solution. This approach was used for deciding the look, feel and appearance of the question bank; whether images were required for a particular question; whether timer was required for a particular set of questions. Some instances are:
    - **Problem Description**: "Why is the computer not saving my file in JCloze?" – *{S1–Subject: English - Group **A** }*
        - **Solution Process:** *I wanted to save my file as "fill in the blanks.jcl" so that it would be easy for me to use the file later. But every time I typed the file name, the computer gave an error of "gap in file name, do you want to proceed? May create problems later?" I didn't understand what was being said, so I renamed my file as 1fill.jcl and it saved it easily. As I wasn't sure about my mistake, I tried 1 fill.jcl when the computer again gave me the error, I understood that file names need to be saved without spaces☺ (*Dated : 27- Feb-2012)
        - **Researcher's Comments:** As one advanced in the use of Hot Potatoes™, one realizes that Hot Potatoes follows the basic HTML rules and there are known issues in HTML where if the image file has a space in between, the servers are not able to display the image correctly. This rule was built into the HotPotatoes™ system, due to which if an image is inserted with a space in its name, it presents it as an error. The way a user can know about this issue, is either by having a bit of knowledge of HTML or by trial and error of file names.
    - **Problem Description**: "My quiz was not able to distinguish between true and false answers." *{ S2 – Subject: Social Sciences- Group **A**}*
        - **Solution Process:** *I was puzzled when I saw the output of my True and False quiz, where all answers were being marked correct by the computer. Not knowing what to do, I redid the whole exercises, only to realize that I was getting the same output. Then I went back to the J Quiz module, and unchecked the true options- It worked fine the first time. But then again I realized in some questions the true answers were also marked false. When I went back to the J Quiz module, I realized, I was supposed to only select the correct answer and not the other options—because of which I was going so so so wrong. (*Dated : 29 – Feb- 2012)
        - **Researcher's Comments:** As JQuiz also allows multi-select questions, if all answers are left checked, JQuiz will not present an error. Hence, the user needs to take appropriate precaution while choosing the correct response (Mark as correct option)
    - **Problem Description**: "I didn't know which module to use for True and False" – {*S3 – Subject: Social Sciences; Group **B**;* }
        - **Solution Process:** *I just could not find where to do true and false. At one point I was wondering if it was a mistake in the instructions given by the Professor....So, I saw again. I didn't find any Hot Potato with True and False. Although when I opened J Quiz I saw the right(✓) and wrong symbols (✗) but no way to do it. I give up. (*Dated : 28 Feb 2012)
        - **Journal Entry Dated 29 Feb 2012:** *I was very excited about coming to the lab. Because I asked my friend where to do True and False and she told me I had to do it in Jquiz...yepieee*
        - **Researcher's Comments:** JQuiz can create four different types of question: multiple-choice/ true or false, short-answer, hybrid (a short-answer question that turns into a multiple-choice question after several attempts), and multi-select (in which the student has to choose several of a set of options, then check the choices). The default action of the software is set at Multi-select questions, and the user needs to change this setting to the MCQ or T/F option to work on those exercises. With a bit of tweaking in the program one can very easily reach this option.

- **Looked for patterns (**where the pre-service teachers tried to look for patterns within their own learning and tasks in hand)
    - **Problem Description: "**Today I spent the whole time, trying to insert image into my file. "{ *S6-Subject- Social Science; Group B*}
        - **Solution Process:** *Then, I remembered from my experience of Open Office Impress and Writer that to insert an image, we first download the image, place it in a folder and then go to the insert option and insert the image. I used the same steps today in JCloze, I first downloaded the picture from the internet, saved it in a separate folder called Images, then went to insert and inserted the image. My image came...But I wanted my image in the centre and that is not happening.* (Dated : 1 March 2012)
        - **Researcher's Comments:** Inserting image in the Hot Potatoes™ exercise is just like other software and the process used by the pre-service teacher is correct.
- **Means- End Analysis (where** the pre-service teacher first analyzed the problem by viewing the end—the goal being sought —and then tried to decrease the distance between the current position in the problem space and the end goal in that space.)
    - **Problem Description: "**Problem of pictures not coming in the HTML file." (*Student 8; Subject Mathematics, Group **A***}
        - **Solution Process:** *When the file was exported to the HTML file, the inserted picture was not visible and without my image, the question had no meaning. So first I tried changing the compatibility in the explorer being used. I also tried inserting smaller size of the image. I also enabled java because I kept getting the msg of Java needs to be enabled. So, I thought that it was the reasons. Anyways, I don't know what was the reason, but in the end, my image was visible in my browser. Thats all I want for now. (* Dated: 2March 2012)
        - **Researcher's Comments:** As discussed earlier, the inserting images require a bit of caution in two parameters: location of the image saved and the file name of the image. If these two are taken care of then, the images are always visible.
- **Other strategies (**here the pre-service teacher was not able to distinguish a software related problem and an educational issue)
    - **Problem Description: "**My J Cross kept crashing today. I kept getting a violation error. Drrats...." {*S4- Subject – English; Group **A***}
        - **Solution Process:** *I was pretty sure today, that I kept getting a violation access that because I had not made the crossword myself and I had plagiarised it from a site. I was baffled at the intelligence of this software, that it was able to detect plagiarised questions too ☹ So I decided to make another crossword all by myself and it worked. I am not pretty sure that this is a very intelligent potato – unlike our real life ones... (*Dated: 29 Feb 2012)
        - **Researcher's Comments:** What the pre-service teacher experienced was a case of software issue, where the software needed to be restarted. But the pre-service teacher mistook this for a case of plagiarism and in fact warned many pre-service teachers about the *intelligence of this software*. Later on a few students tried to debunk this myth that the software was able to detect plagiarised crossword, but somehow the access violation error surprised many. The result was that many pre-service teachers made their own crosswords ☺ After the completion of the study the researcher explained the cause of the error and clarified it was not about plagiarism.
    - **Problem Description: "**My crossword is not looking like others crossword." {*S5; Subject – Science; Group **B***}
        - **Solution Process:** *When I see my crossword, it looks not like others. I don't know what to do. I tried to add clues nothing happened. I asked my friends and no one knows my mistake. I cannot show my file to anyone. I am leaving it for you Madam to tell me what is not good with crossword of mine. (** English as per Journal entry* dated: Not mentioned in the Journal*)*
        - **Researcher's Comments:** The Pre-service teacher was not able to differentiate between a Crossword and Word Maze. The teacher made a maze and was not able to get the look of a crossword as all the blanks were filled with redundant alphabets. The researcher did not correct this error when spotted, because it is expected that pre-service teachers know various methods by which they can impart instruction or conduct test.

Implications

The present study focussed overtly on the various problem solving strategies used by Pre-service teachers to develop an Online Question Bank using Hot Potatoes™; while covertly it also aimed at also seeing whether the pre-service teachers were able to translate their pedagogical content knowledge into a technology based environment, harnessing the potential that technology has to offer to education and educationist. This study has two major implications:

1. **Strengthening Teacher's TPCK**: Koehler and Mishra(2009) state that TPCK is the basis of effective teaching with technology, requiring an understanding of the representation of concepts using technologies; pedagogical techniques that use technologies in constructive ways to teach content; knowledge of what makes concepts difficult or easy to learn and how technology can help redress some of the problems that students face; knowledge of students' prior knowledge and theories of epistemology; and knowledge of how technologies can be used to build on existing knowledge to develop new epistemologies or strengthen old ones. Working with Hot Potatoes™ allows the teachers in the classroom to present students with interesting learning environments for testing. This environment can be used for additional practice tests and can be taken by the students whenever they wish to practice. As Hot Potatoes™ can also be used for remedial and enrichment lessons; knowledge of this tool is an asset to the teachers. Working in a self-learning, technology rich problem solving environment gives the teachers confidence to work and explore new tools in education and make their classes interesting.
2. **Strengthening Teacher Education Curriculum** by including activities for teachers following the paradigms of Constructivism, Problem Solving Modules, Individualized learning experience, Confidence to experiment with Technology: Present day teacher education curriculum presents the above mentioned activities as theoretical constructs and does not provide the teachers with experience to work in such paradigms. In this study, using problem solving strategies, pre-service teachers themselves learnt (*Constructivism)* the various ways and uses of adapting Hot Potatoes™ in their subject areas. Pre-service teachers gained confidence to explore technology and find out ways in which they are able to rectify their own mistakes – a very essential step when we learn any new software.

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Mixed and Added Realities: Development and Use of Web-Based Learning Module for Technology and Natural Science Educators

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Teachers and lecturers continue to grapple with the best ways to teach and learn Science and Technology using current information and communication technologies (ICT). This paper presents an introductory process of developing web-based module for technology teacher education students using Web-CT and animation tools for the effective teaching of electro-chemistry that has remained a problem to Natural Science educators in South Africa. Two research questions: how can a web-based learning module be developed to enhance technology education? And what necessary steps can be practically taken in the use of animation to enhance the work of Natural Science educators? were addressed. One main hypothesis: `the use of mixed and added realities involving the development of Web-based learning module and animation enhances the performance of technology and Natural Science educators` was tested. The design was a quasi experimental type of non-equivalent pre- and post-tests control groups and the mixed method with material development and teaching 58 learners. The main result showed that the approach of this study actually enhanced the performance of the educators and the learners in the experimental group. The study recommends the adoption of the results and increased number of subjects for possible replication elsewhere.

Introduction

Recent technological developments in information and communication technology are adding new dimensions to the strategies and instructional tools available for teaching learning. Computer technologies provide a rich learning environment that exposes the learner to a variety of representations and configurations, such as realistic models, graphics and simulations (Doppelt, 2005). The capability of computers has enabled the teaching of hands-on technology and science laboratory courses which should normally use tools, equipment and machines to be easier by computer-based virtual demonstrations. Such opportunities have reduced a range of problems for students in the areas of inadequate number of apparatus, equipment and tools, safety issues, inability to use some of the tools and equipment, and time constraints in completing hands-on projects (Borchert, 1999; Agyei-Mensah and Ndahi, 2006).

It is noteworthy to observe and agree with Owston (1997) that nothing ever captured the imagination and interest of educators simultaneously around the globe more than the World Wide Web (www). The web has become a special tool that causes teachers at all levels to re-think of the very nature of teaching, learning and schooling. Web is fast making waves in making learning more accessible through graphical screen layout, interactive multimedia learning materials, simplified access to and searching of databases, exponential growth of new resources around the world, and open technical standards that allow any modern computer to access the web (Owston, 1997).

To respond to the increased demands for technological literacy (Pearson and Young, 2002), by the use of ICT in teaching and learning has become imperative. Hence, schools and universities are gradually employing ICT in teaching, learning and assessment to cope with large classes and lack of laboratory resources. Students of the new generation are expected to display some valuable skills as critical thinking, problem-solving, written communication, and the ability to work collaboratively. This is to be able to face the challenges posed by the new global economy, where the knowledge and skills of a nation`s workers are the key to its competiveness among others, rather than factors such as natural resources and geographical location that reigned supreme in the past. Changing clientele, increased student numbers, and decreased staffing are situational barriers to quality teaching and learning.

The introduction of ICT is therefore seen as one way to overcome the barriers observed and to provide cost-effective facilitation of transformative learning where students can manage their learning in a flexible and individualized way. Indeed, the Web provides flexible learning. As a show of possibility, the Oregon State

University successfully offers Philosophy 201 entirely by on-line, using the Web and electronic mail (http://www.cs.orst.edu/department/instruction/phil201.S95/). This effort goes a long way to enhance student autonomy and intellectual community and to create a self-paced, expert-directed, time/place independent environment for learning (Owston, 1997). All readings required of the students are made available on the Web including debate issues raised during the course in electronic virtual conversations. The teacher and students interact via emails and broadcasts for necessary feedbacks. The level of success registered by Oregon State University is implied in their ability to use a mixed method approach not to remove themselves from the educational process. Their role became more of creating learning experiences for the students than just delivering of instructions to academic guides. Bates (2001) identifies the following advantages of using the Web in learning:

- its ability to combine text, and graphics;
- the Web enables free and global access to a very wide range of high quality (as well as low quality) learning resources located on the Web sites;
- the Web offers opportunities for international, cross-cultural and collaborative learning;
- the Web enables students to study at any time and, increasingly, from any place; and
- the Web allows asynchronous (time-delayed) interpersonal communication, not just between lecturer and student, but more importantly, between students and other students, through e-mail, bulletin boards and online discussion forums (Bates, 2001).

The nature of teaching changes with social-historical conditions, with information technology an emerging feature of teaching (Clift, Mullen, Levin, & Larson, 2001). Natural science teachers including Chemistry and Technology) must make much effort to create an ideal environment for teaching and learning. Including technological tools in the classroom will require teachers to employ different teaching techniques. In the recent times, studies on the effects of technological tools on learning and teaching have begun to make use of Dual coding theory and cognitive load theory (Pekdağ, 2010) and are both good pointers to need for the use of variety of teaching techniques with appropriate augmentations.

It is well known, even according outcomes based approaches that students should be engaged in active (Lunenberg and Volman, 1999), self-directed (Tillema, 2000), and self-regulated (Kremer-Hayon and Tillema, 1999) learning. In teacher education programmes, constructivist pedagogies promote the creation of knowledge (Gibbons et al., 1994; Holt-Reynolds, 2000). Reasoned dialogue rather than instructional dialogue mediates knowledge. The student-teachers need to transform knowledge rather than reproduce what the teacher says. There is minimal understanding, of what and how teachers integrate knowledge into frameworks that guide their practice (Schoenfeld, 1999). According to Beijaard et al (2000), teachers derive their competence from how they see themselves as experts in subject matter, pedagogy (how teachers engage with students), and didactics (how teachers plan, present, and assess lessons). Active and independent learning is being promoted within each of these factors identified as contributors to teacher education: subject matter that is transformed into teachable knowledge, pedagogy that aims to enhance students learning outcomes, and didactics that facilitate students' knowledge construction and use. Many countries have developed and implemented technology education, for example, in 1992 Botswana developed a national curriculum policy in which Design and Technology (Technology) became one of the eight core subjects (Molwane, 2002). In 1990, England introduced Design and Technology into schools (McCormick, 2002). The quality of technology education programmes is greatly determined by the successful students having acquired the skills, knowledge and values needed by society, more specifically the workforce (Frantz et al, 1996). Curriculum reform in technology education seeks to modify the traditional laboratory and workshop-based science and technical courses from the usual focus on industrial hand and machine skills to a more emphasis in critical and creative higher order thinking skills (Walmsley, 2003).

This definition, in common with international statements, stresses the importance of providing students with opportunities for participation in meaningful learning experiences in which they could draw upon their existing knowledge of materials, tools, machines, and systems, as well as gather and use information from a variety of sources. The meaningful learning experiences should facilitate the engagement of students in problem solving to produce an end process, product, or artifact, thus enabling their construction of new and deeper understandings of technology concepts and processes (Davis et al, 2002). The technology education learning outcomes and assessment standards reflect the attainment by students of range of problem solving skills, manipulative skills, and in particular, understanding technology concept knowledge (Department of Education, 2002). The following skills are essential to advance technological literacy now and in the future:

- Skills of analyzing and problem solving
- Skills of information-processing and computing

- An understanding of the role science and technology in society, together with development of scientific and technological skills
- An understanding of and concern for a balanced development of the global environment
- Communication and entrepreneurial skills
- A capacity to exercise judgment in matters of morality, ethics, and social justice (Martin, Dakers, Duvernet, Kipperman, Kumar, Siu, Thorsteinsson, & Welch, 2003)
- Designing and making skills (Pimley, 2004)

In the final analysis, the critical outcomes of natural science and technology aim at enabling the learners to:

- communicate effectively using visual, mathematical and language skills;
- identify and solve problems by using creative and critical thinking;
- organise and manage activities responsibly and effectively;
- work effectively with others in a team, group, organisation and community;
- collect, analyse, organise and critically evaluate information;
- use science as technology effectively and critically, showing responsibility towards the environment and the health of others; and
- understand that the world is a set of related systems.

The main focus or problem of this paper is to demonstrate the introductory process of developing web-based module for technology teacher education students using Web-CT and animation tools for the effective teaching of electro-chemistry that has remained a problem to Natural Science educators in South Africa. Two research questions were thus raised for the study as (1) how can a web-based learning module be developed to enhance technology education? (2) What necessary steps can be practically taken in the use of animation to enhance the work of Natural Science educators? The hypothesis stated was that `the use of mixed and added realities involving the development of Web-based learning module and animation enhances the performance of technology and Natural Science educators`. Animation is the rapid display of a sequence of images of 2-D or 3-D artwork or model positions in order to create an illusion of movement (http://en.wikipedia.org/wiki/Animation, 2011).

Methodology and Design

We made use of a quasi experimental non-equivalent post-test control groups design on two groups of pre-service natural science and technology students from two Universities in Pretoria, South Africa. This research design was chosen because it provides a platform to determine differential effects of phenomenal changes in any cause-effect study. A non-randomized sample of 58 made up of 31 (18 and 13) students in the experimental groups and 27 (17 and 10) students in the control groups was used. The student-participants, though most of whom were adults, volunteered to take part and none of them was constricted to be part of the study in view of ethical requirements. The method involved the demonstration of the process of developing a web-based module for technology education and animation tools. The researchers then applied these tools in teaching selected aspects of electro-chemistry to the sample students in the experimental groups while students in the control groups were taught without such mixed and added realities for six weeks. Data were collected with the use of well-structured questionnaire to be able to answer the research questions and post test scores of the students on electrochemistry (from AIEEE Chemistry Redox Reactions and Electrochemistry online Test 2011 at *http://www.wiziq.com/tests/chemistry-electrochemistry* and selected questions from different years at *http://apchemistrynmsi.wikispaces.com/.../Electrochemistry+FR+worksheet...*-) were analyzed to test the stated hypothesis.

Module Content and Context

The technology teacher education programme is a full contact qualification; however, the web-based learning is developed to offer the recipients an alternative and added innovative way of le,arning. The module content is presented on the Web, providing information on its Website. Students tackle learning activities at their own time and environment (library). The lecturer is fully aware that students have a limited access to computers, both at home and at the institution. The environment uses a problem-based approach to teach theoretical and practical task for using the Web to present, manage and facilitate resource-based learning (Cronje′, 2001).

Design of the Context

The design is based on a constructivist theory embedded in the learning activities. It is popularly known that learning is an active process of knowledge construction on the part of students. This has led to the popularity of constructivism as an instructional approach to learning (Reddy, Ankiewicz and de Swardt, 2005). In Web-based learning environments, learning occurs through navigating the learning content on the web. Lee and Baylor (2006) noted that students experience disorientation with these non-linear contexts. This type of orientation is often observed in learning, and can notably limit instructional effects (Collis, 1991). It is believed that metacognitive map can support students' orientation within the learning content (Lee and Baylor, 2006).

Web classroom

The Web-based classroom design should provide a more attractive and interactive environment for students to learn. Although the virtual environments cannot replicate contact-teaching, the designer should portray the objects and events of a typical classroom. The learning content and the learning activity should be reviewed every year to be up to date with latest developments in the field of study. Figure 1 shows the home page of a Web classroom with the following parts:

1. Buttons, which link to learning outcomes, learning activities, assessment criteria, presentations, internet, formative assessment, summary, assessment criteria. Clicking on them provide information similar to lists on notice boards or printed material.
2. Resources centre provides a place for downloading conventional lecture notes or viewing short video clips for better understanding of each topic. The section attracts attention, generates interest to learn, and facilitates students' understanding.

Students will be able to apply the theory learned to finish the assignments and tasks. To assess what students have learned from the content, there are automatically marked short quizzes. Students must answer correctly to certain high percentage before moving to the next unit.

Analysis, Findings and Discussions

To answer the first research question that says how can a web-based learning module be developed to enhance technology education? 49 (84.5 percent) of the 58 subjects affirmed that a proper way of developing any web-based learning module must be in categorized steps. According their responses, the steps are as follows:

- Determining appropriate topic taking into consideration the three key learning outcomes areas as *technological processes and skills; Technological Knowledge and Understanding; and Technology, Society and the Environment* in agreement with the South African policy (Department of Education, 2006).
- Determine Assessment standards, designs and plan for the topic.
- Generate and communicate at least 2 innovative design solute-ions that solve the problem, using appropriate communication techniques and make a choice of one of these through valid argument. Develop a list of materials, tools, equipment and sequence of manufacture they might use in making their product using simple presentation techniques.

The second research question: What necessary steps can be practically taken in the use of animation to enhance the work of Natural Science educators? was answered by 53 (91.4 percent) of the participants in the almost in the same manner.

- It was clear to them that a major step is being computer literate by both teachers and students. The teacher is expected to declare the objectives of any topic to be animated in such a manner that text and object animations are a compelling way to positively punctuate his/her message.
- The teacher is further expected to be able to fine-tune his/her animations by setting the duration, choosing which element is affected first, and defining the animation path along a straight line or a curve.
- Both teacher and students should be able to achieve some impressive animations with basic programs; an animation database is a database which stores fragments of animations which can be accessed, analyzed and queried to develop and assemble new animations thereby further creating knowledge.

The stated hypothesis was tested using mean score (x) and standard deviation values to determine differential effect in performance between the students taught with mixed and added realities in the experimental group and those taught the same topics in the control group in the conventional way.

Group	Number (N)	Mean Score (x)	Standard Deviation (SD)
Control	27	52.44	7.32
Experimental (Web-Based)	31	83.68	6.47
Sum (N)	58		

Table 1. Mean Scores (x) and Standard Deviations (SD) of Pre-Service Technology and Natural Science Educators` Performance Test (PSTNSEPT)

Table 1 above shows a total of 27 Pre-service Technology and Natural Science educators that were taught electrochemistry lessons not based on the use of Web-teaching and learning in the control group. Their mean score is 52.44 in the post performance test compared to the 31 educators in the experimental group with a mean score of 83.68 in the post test after being taught the same topics using the mixed and added realities (Web-based learning materials and animations). A considerable lower standard deviation of 6.47 for the experimental group compared to 7.32 of the control group proves that there is a great advantage in the use of carefully developed Web-based learning materials including animations to enhance the performance of the educators and learners in the experimental group.

Conclusion

This study aimed at the use of mixed and added realities through the development of learning modules and Web-based materials to enhance the tasks of technology and Natural Science educators especially in the teaching of electrochemistry. We believe from this study that no one method of instruction is the best, but that there are methods and strategies to be employed in the design of Web-based learning environments that help to bridge learners and reduce feelings of alienation (Dickey, 2004). In agreement with Dori, Barak and Adir (2003), we discovered that students strongly favoured the use of web-based activities in the study of technology and chemistry in general. According to the students, they gained wider experiences with higher knowledge retention as they kept on working as individuals and sometimes in groups at their own pace and time as they could repeat such activities as often they would want. This study found out increased interest in the students about the study of electrochemistry as they virtualised the activities of ions and molecules with slightest efforts. This proves why the experimental group performed significantly better than the control group in the post test and hence, Information Technology (IT) significantly enhanced the performance of the educators. We therefore recommend that the use of mixed and added realities in the form of animations, simulations, web-based learning modules should be given the right place in the teaching and learning process particularly for science and technology courses to help reduce the usual abstractness associated with such courses.

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Cellular Phones in the Mathematics Classroom: Experiences from South Africa

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This paper reports on a recent South African research project that investigated how teachers made use of cellular phones to support their teaching of Mathematics through the incorporation of VITALmaths video clips (http://www.ru.ac.za/VITALmaths). VITALmaths video clips are visually and intellectually appealing, short in duration (1-3 minutes), and are produced using a stop-motion animation technique that purposefully makes use of natural materials as opposed to high-tech graphics. Each video clip develops a specific mathematical concept or process, with the emphasis on teachers and pupils using the video clips as autonomously and independently as they wish. The heart of the research project lies in the study of how teachers incorporated the use of cellular phones into their classroom practice to support the teaching of Mathematics. This study contributes to contemporary teaching strategies by bolstering teachers' repertoire of pedagogical practices.

Introduction

In 2004, in response to international trends, the South African government established ambitious goals with respect to policy surrounding Information and Communication Technology (ICT) implementation at school level. While acknowledging the magnitude of the task of delivering functional ICT infrastructure, equipment and appropriate support to all schools in South Africa, the White Paper on e-Education (Department of Education, 2004) nonetheless proposes that by 2013 all schools, teachers and students should be confident and competent users of ICT, and that ICT should be integrated into teaching and learning at all schools in South Africa. Notwithstanding the clearly delineated policy goals of the South African government, ICT rollout and implementation in most South African schools has been a slow process, one fraught with financial, administrative and logistical complications. By way of example, the 2009 National Education Infrastructure Management System (NEIMS) Report (Department of Education, 2009) highlighted that of the 24,460 public schools in South Africa, only 5,714 (23%) had computer centres of some description, while only 2,449 (10%) had computer centres that were stocked, functional, and could be used for teaching and learning. Perhaps somewhat disturbingly, this situation exists despite vigorous collaborative efforts by government, the private sector, non-governmental organizations (NGOs) and local communities to provide ICT infrastructure and equipment to schools in South Africa.

On a more encouraging note, despite the remoteness of many rural schools in South Africa, almost 92% of all public schools are covered by cellular phone communication systems, compared to only 13% that have internet connectivity (Department of Education, 2009). Given that cellular phone signals reach 99.97% of the South African population, and that the cellular phone saturation rate is close to 100%, cellular phones represent an affordable, reliable and readily available alternative to more conventional forms of ICT within the educational arena. This opens up exciting educational opportunities, particularly for under-resourced or rural schools that are typically characterised by their poor ICT infrastructure and geographical remoteness. The use of cellular phones in the educational arena has the potential to provide immediate solutions to the problem of slow and expensive ICT rollout. As Selanikio (2008) pertinently remarks, "…for the majority of the world's population, and for the foreseeable future, the cell phone is the computer" (p. 2).

VITALmaths

The rapid growth in the South African cellular phone market, coupled with widespread network coverage and support, has opened up the potential for new learning experiences and opportunities as well as providing access to educational resources well beyond those traditionally available. This was one of the opportunities taken up by the VITALmaths project (Linneweber-Lammerskitten, Schäfer & Samson, 2011). VITALmaths is a multilingual collaborative research and development project between the University of Applied Sciences Northwestern Switzerland (FHNW) and Rhodes University in South Africa. The VITALmaths project produces and disseminates short video clips that can be viewed on a cellular phone, and which are specifically designed for the autonomous learning of Mathematics. These video clips are visually and intellectually appealing, short in duration (1-3 minutes), and are produced using a stop-motion animation technique that purposefully makes use of natural materials as opposed to high-tech graphics. Each video clip develops a specific mathematical concept or process, with the emphasis on teachers and pupils using the video clips as autonomously and independently as they wish. A number of projects within South Africa have already harnessed the ubiquity of cellular phones to support the learning of mathematics: *ImfundoYami/ImfundoYethu* (Vosloo, 2009), *M4Girls* (Vosloo, 2008), *MOBI*™ (Botha, 2007; Vosloo, 2007) and *Dr Math* (Vosloo & Botha, 2009). The VITALmaths project adds to this growing endeavour of utilizing cellular phone technology to support the teaching and learning of mathematics, particularly in rural/remote or under-resourced contexts. The research reported on in this paper focuses on how teachers made use of cellular phones to support their teaching of Mathematics through the incorporation of VITALmaths video clips.

theoretical considerations

The research project (Ndafenongo, 2011) reported on in this paper embraces a social constructivist theory of learning in which learning is seen as an active process in which meanings are constructed socially and culturally through individuals interacting with each other and with their environment. Elements of particular importance are (1) learning as an active process (Von Glasersfeld, 1983, 1989), (2) exploration (Cobb, Yackel & Wood, 1991), and (3) learner autonomy (Dam, 1995 as cited in Chan, 2001, p. 506).

Learning as an active process

"Learning mathematics is as much about *doing* it is about *knowing*….. Technology can change the nature of school mathematics by engaging students in more active mathematical practices such as experimenting, investigating and problem solving that bring depth to their learning" (Goos, 2010, p. 68). Olive and Makar (2010) argue that mathematical knowledge and mathematical practices are inextricably linked, and that this connection can be strengthened by the use of technologies. Furthermore, as Ramaley and Zia (2005)argue, the new generation of students is experiential, engaged and have a strong need for immediacy. The use of cellular phones in the Mathematics classroom, if appropriately employed, has the potential to heighten this sense of experiential engagement and immediacy.

Exploration

The National Educational Standards in Switzerland (Weinert, 2010 in Linneweber-Lammerskitten et al., 2011) and the Revised National Curriculum Statement in South Africa (Department of Education, 2003) both place emphasis on mathematical exploration as an important approach for learning mathematics. The VITALmaths video clips are produced fundamentally to support and encourage genuine mathematical exploration (using natural materials that learners can source locally) by encouraging a desire to imitate, experiment, use trial-and-error, formulate conjectures and generalize results (Linneweber-Lammerskitten, et al., 2011). In this way even students with weaker mathematical ability can be exposed to challenging but interesting mathematics.

Autonomy

Teachers cannot directly provide learners with an experience of autonomy (Reeve & Jang, 2006), but rather they need to provide genuine opportunities that encourage, nurture and support autonomous learning. VITALmaths project which produces the video clips used in this study foregrounds the importance of autonomous learning (Linneweber-Lammerskitten, Schäfer & Samson, 2010). As Mousley, Lambdin and Koc (2003) succinctly comment, "Autonomy is not a function of rich and innovative materials themselves, but relates to genuine freedoms and support given to students" (p. 425). Thus, critical elements of the design principles of the video clips take into account both cognitive and non-cognitive dimensions. use of cellular phones can promote learner autonomy through learner control ≅ learners have full control of their own speed in watching the videos as well as trying them out and re-watching them if necessary. Learners can thus take greater control over the learning process, thereby promoting independence, enthusiasm, and a sense of satisfaction (Stemler, 1997). It is important to clarify here that within the context of social constructivism, autonomous learning is not seen as being restricted to an individual learner making decisions in isolation. Furthermore, therole of technology in the classroom is by no means meant to replace the teacher but rather to support the teaching process in terms of efficiency and to encourage participation and active engagement.

Methodology

The research project (Ndafenongo, 2011) reported on in this paper explored teachers' and learners' experiences in using short mathematical video clips viewed on a cellular phone in the classroom[1]. The study was qualitative in nature and was grounded in an interpretive paradigm (Babbie & Mouton, 2001). A case study methodology was adopted, the case under study being two Grade 10 classroom environments, one in each of two schools in the Eastern Cape region of South Africa. Since the purpose of the study was to capture the complexity of teachers integrating cell phones into their teaching repertoire, the analysis focused on the experiences of the participating teachers and learners as well as the classroom dynamics observed during the course of the teaching experiment. In addition to classroom observations (which were video recorded) and individual interviews with the teachers, focus group discussions were also conducted with the learners.

An initial workshop was held with the participating teachers in order to familiarise them with the VITALmaths video clips. An orientation lesson was then held with each of the two Grade 10 classes in order to acquaint both teachers and learners with the experience of using cellular phones in a classroom setting, since this was a novel experience for them, as well as to familiarise both the teachers and learners with the particular cellular phones that were going to be used (30 identical smart phones were sponsored by a leading cellular phone network company in South Africa). Each of the two teachers then designed a 3-lesson sequence on the Theorem of Pythagoras using five VITALmaths video clips (see also Samson & Ndafenongo, 2011) that focused on that particular topic (interested readers can view and/or download these five video clips, as well as others, from www.ru.ac.za/VITALmaths). These two 3-lesson sequences formed the focal point of the study.

Data from the recorded lesson sequences as well as the teacher interviews and learner focus group discussions was then used to identify important themes. Themes gradually emerged from the data, and were refined over time with repeated engagement with the data. Themes were grouped to provide a rich characterization of learners' and teachers' experiences with using cellular phones in the context of the Mathematics classroom.

Results

The data analysis process involved repeated engagement with the data using an iterative approach. Important themes that emerged during this process included: participation, engagement and collaboration; autonomy; affective aspects such as motivation; dynamic visualization; hands-on activities; and teacher enrichment. Each of these themes is discussed below. Although the themes are presented individually, it is acknowledged that they are complementary, interrelated and overlapping.

Participation, engagement and collaboration

A strong finding running through classroom observations as well as the responses of both teachers and students is that there was active participation and excellent engagement in the lessons that incorporated cellular phones. actively wanted to make sense of what was being viewed on the cellular phone in order to be able to follow and reproduce the activities themselves. In addition, teachers pointed out that students were willing to participate and share their findings/solutions with the teacher and other students which in turn served as a motivation to other students and provided valuable feedback to the teacher. Overall, there is strong evidence to suggest that cellular phones enhanced students' participation as well as collaboration.

Autonomy

Learners found that watching and interacting with dynamic pictures on a cellular phone led to an experience that was far more than simply having a teacher give verbal instructions. Learnersparticularly appreciated that they were in control of their learning by holding the medium of instruction in their hands since this allowed constant opportunity for them to re-watch the activity in order to grasp the content at their own pace. Learners were thus afforded the opportunity to work at a pace with which they felt comfortable, and which each student had direct control over. This aspect supported both faster and slower students. As a result, in those lessons where activity sheets were used in conjunction with cellular phones, students were able to work much faster on their own without constant recourse to the teacher's instructions.

1 On a note of clarity, although the video clips could equally be played on a laptop computer, tablet or desktop PC, or indeed any other available video playing device, for the purposes of this study the cellular phone was specifically used as the video playing device of choice given the particular ICT context described in the introduction.

Affective aspects such as motivation

A solid finding running through the data related to the affective domain of the students' experience. The environment created through the use of cellular phones not only contributed to active participation but also created a space for students to feel comfortable and confident. Students who were usually shy or reserved were observed to have been participating far more readily and enthusiastically than normal.

Dynamic visualization

The VITALmaths video clips used in this study purposefully made use of striking visual approaches to explore various mathematical themes and ideas. This dynamic visual element was greatly appreciated by the learners since they were able to see how things were carried out rather than simply being given verbal instructions. Thus, an important aspect of using cellular phones in the classroom for displaying video clips was that each student was afforded the opportunity to be able to *see* the mathematics.

Hands-on activities

The practical or hands-on nature of the cellular phone lessons was highlighted by participants as being an important feature that contributed to the success of these lessons. Teachers particularly appreciated that the VITALmaths video clips exposed their learners to hands-on activities. This in itself was a marked difference to what their learners usually experienced in the classroom. The hands-on nature of the lessons was at least in part responsible for keeping students busy, engaged and focused. Learners also appreciated that they were able to investigate and explore scenarios using physical materials rather than simply having these related to them verbally.

Teacher enrichment

The notion of teachers themselves being lifelong learners found resonance with the use of VITALmaths video clips. The participating teachers commented that by engaging with the video clips they furthered their own mathematical understanding and conceptualization. As teachers continue to engage with new material and pedagogy, their effectiveness as teachers should grow and develop. VITALmaths video clips are a valuable resource to add to this experience of lifelong learning by affording teachers the opportunity to improve their mathematical content knowledge as well as their pedagogical content knowledge. This is particularly important for remote and under-resourced schools.

Discussion

As with most pedagogic approaches and technologies used in education, the teacher's role during the lessons with cellular phones was crucial. The teacher had the responsibility for choosing and sequencing activities as well as guiding the lesson in the desired direction. More specifically, the teacher was responsible for proper planning, familiarization with the video clips, connecting the lesson to previous concepts, pacing students' activities in class, and giving and directing attention towards the students who needed the most encouragement while keeping the overall lesson moving forward. Having VITALmaths video clips and cellular phones as resources in the classroom does not immediately solve all the problems inherent in an under-resourced classroom, or indeed any classroom. However, the study did find that that the use of cellular phones and the VITALmaths video clips strongly supported the pedagogical endeavour by freeing up time normally spent on lesson delivery, thereby enabling teachers to attend more easily and more often to individual students or small groups rather than addressing the class as a whole.

In terms of the role of the teacher, the study highlighted the importance of teachers being familiar with the cellular phones and having a thorough understanding of the VITALmaths video clips in order to be able to guide, assess and direct the learning. In addition, using carefully prepared worksheets in conjunction with the video clips proved to be an effective means of promoting student autonomy in that it allowed students to carry on the learning process at their own pace and with minimal instruction from the teacher.

Concluding Comments

This study contributes to contemporary teaching strategies by boosting teachers' repertoire of pedagogical practices, specifically the use of VITALmaths video clips and the use of cellular phone technology in the classroom setting. It is hoped that through this research students and teachers will be inspired to make use of the freely available databank of VITALmaths video clips, not only in the classroom setting but also in nontraditional learning spaces where having instant access to the video clips will enable them to take advantage of the spontaneity of a given moment.

On a note of caution, cellular phone technology and associated resources such as the VITALmaths video clips should not be seen as ends in themselves. Rather, they are teaching and learning resources that still require the artistry of a skilled teacher. Keeping this in mind, the present study nonetheless shows that cellular phones represent a viable alternative to more conventional forms of ICT in under-resourced schools. This is significant since in most township or rural schools there are still insufficient computers and associated infrastructure for each student to experience authentic learning through ICT.

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