Reconstruction of Phenomena through STEM Games

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1 Introduction

At the outset, I wish to congratulate the Breakthrough Science Society for organizing this event, and in Kolkata. It was at this city several decades ago, India made a 'breakthrough' in science, at the Indian Association for the Cultivation of Science, when we had at that time seven Fellows of Royal Society. We need to reflect on what happened after Independence, that we could neither conserve nor accelerate despite the initial impetus.

I would like to clarify the use of "STEM", in place of "science" in the title of the talk. The view that I am arguing for in this presentation highlights the role of technology, engineering, and mathematics in reconstructing natural phenomena by scientists. This is also an invitation to the scholars in the area, to approach the structure and dynamics of scientific knowledge as a network of inter-dependent layers of a socially situated inquiry.

During the talk, I would first present the view that the activities of scientists be interpreted as rule-following activities, as STEM games. As a part of the STEM games, scientists have been involved in searching for the *building blocks* and *cement* for reconstructing natural phenomena. This reconstruction happens in an artificially constructed experimental "microworlds". And in this reconstruction process, I would argue, that scientists have always been employing technology, engineering, and mathematics. The evidence for the truths in science is situated in the socially reconstructed experimental process of natural phenomena, and cannot be obtained in isolation.[2]

2 STEM Game as a Cultural Game

The organic character of scientific practice can best be understood by attending to the relationships between *culture* as *games* and *science*. Many of us agree that science is a subculture. Games are part of the cultural practices, including music, dance, and art.[8] Unlike other cultural practices, where the rules are implicit or tacit, in scientific practice the rules should always be stated explicitly. This makes science a powerful inter-subjective game. Another interesting point here is when scientists think, imagine or formulate an idea, they do that in a restricted space. They create the objects-to-think-with only in that restricted space. They create the model of phenomena within that restricted space. The rules of the model also restrict the objects and their predefined actions within that closed boundary. This is one of the significant epistemic aspects that come out loudly as model-based reasoning. I would suggest that this gaming character should be one of the important topics to be explored by scholars involved in the philosophy of science.

As a science education researcher at HBCSE, TIFR, I always have this concern: "Is there a clear implication of philosophy and history of science to science education?" What should we tell a science teacher to do in a classroom or in a lab about what or how should science be practiced? The role of engineering and technology could not be undermined when we talk about science. Science always needs validation, whether it is bosons or gravitational waves. We always validate these ideas with the help of technology, engineering, and mathematics. Despite this, there are very few philosophers of science who engage with the essential epistemic role played by engineering, technology, and mathematics.

3 STEM Game as a Construction Game

I want to underline the use of the word "construction" instead of the widely used terms in philosophy of science such as explanation, discovery, proof, evidence, prediction, verification, falsification, etc. It is important to use concrete terms like "construction" to avoid ambiguity.

If we look at the history of science, we will find that the search for the building blocks has been there for a long time. Search for the structural and functional units, from atoms to genes to memes, extending physical, biological and cultural layers of our world. Apart from the building blocks, scientists also looked for the mechanisms; scientists proposed various laws and theories. I will use the term "cement" for it. The reason behind using this term is to make my "construction game" apter, with bricks and cement as metaphors.

A very successful story in science is that we have discovered most of the building blocks for all the ontological levels of the world: atoms to molecules, amino acids to proteins, genetic code to genes, bits to programs, alphabets to words, agents to societies, etc. One crucial part of this game is: how to generate diversity from a minimal set of basic elements. It is the idea of reductionism: to break down the phenomena into smaller parts, analyze these blocks, give explanations for the working of these building blocks, superimpose the behavior of the building blocks and we have the account for the whole system. The better we know about the building blocks, the better we understand the entire system. This is one part of the construction story.

Unfortunately, the reductionist narrative doesn't work for all the phenomena. We can't explain the physiology with an understanding of biochemistry alone. Knowing physiology doesn't explain organic evolution. In most of the cases, knowing lower levels doesn't provide fuller explanations of the phenomena on higher levels. “The whole is more than the sum of its parts.” Interestingly, the quote is quite ancient, it is from Aristotle himself. We threw his baby with the bathwater (which included his incorrect explanations in physics), without understanding the full implications.

Let’s go back a few generations before Aristotle, to understand the initial breakthrough in science. Anaximenes and Pythagoras, soon after Thales, came up with a ‘cement’ for our construction business. Anaximenes considered the relationship between the entities, whatever they could be. In his view, the substance from which the world is made of wasn’t as important as the relationship between them. To him “the matter doesn’t matter, the relationships between them do”. Pythagoras took this idea further. The most viable way to think about it is to build a “microworld” made only of relations. By regarding numbers themselves as patterns of relations, the relations between the numbers as properties of them, Pythagoras became almost a mystic by constructing and living in the constructed ’microworld’ of numbers.

Though Plato and Aristotle constructed, rather successfully, conceptual and logical microworlds respectively, their attempts in constructing natural phenomena through concepts, logic, and language did not work.

Interesting breakthroughs happened in Alexandria through Euclid and Archimedes, arguably the first paradigm cases of real and replicable STEM games. Euclid constructed a world by employing only a ruler and a compass. The geometers of the period made various possible geometric objects and studied the relation between them within that “microworld”. Given the ruler and compass, a microworld of a geometrical plane was constructed. Mathematicians who got an entry into this microworld were enamored by the ‘beauty’ and simplicity. When new geometrical objects or their properties were realized, we could check if the features of them can be really replicated by reconstructing them from the rules. The possibility of *constructing a proof* made them truly game-like.

The Euclid’s ruler became a lever in the hands of Archimedes, who is arguably the first mathematical physicist. He continued the game of reducing unknown to known. Grasping the mechanical advantage of the principles of the lever, Archimedes constructed several machines. Compass became a ruler with a pivot. A large number of simple machines were constructed, including warfare, expanding the peri-personal space as well as the mechanical advantage of human beings by several folds. Simple machines were in use before Archimedes, but now he demonstrated why they work, making him proclaim: give me a place to stand and long enough lever, I can lift the earth!

4 Externalization of STEM Games

Now, we shall take a jump to talk about Alan Turing, though so much happened between Archimedes and Turning. In his short life, he laid the foundation to the design and fabrication of “thinking machine”. He proposed a mathematical model for an automated machine with very few basic rules like having a memory-tape with finite or infinite length, a head capable of reading and writing 1 or

0, moving the tape in either direction on the tape. With just these handful of rules, a Turing Machine could compute anything computable. The various digital tools we use today were faster and more efficient extensions of a Turing machine. Turing's proclamation, along the lines of Archimedes, was: give me a long enough tape to encode and decode, I can construct thinking machines.

Before Turing, we constructed machines mostly out of a complex combination of levers and wheels. And constructed symbolic representations that required a human interpreter/calculator. By pushing calculation out of the human body, and by proving that mapping calculation is nothing but interpretation, the thinking was pushed out of the human body. Human beings were using externalized memory from time immemorial, but it is only after Turing we started externalizing interpretation of memory as well. The modern digital society is a complex superposition of language, machines, and computers, all part of the story of the STEM games.

5 STEM games with externalized Agents

Seymour Papert, after working with Jean Piaget, founded the MIT Media lab with Marvin Minsky at Boston. Papert introduced the term "constructionism" and popularized the idea of "microworlds".[3, 5] He made the so-called abstract mathematical ideas concrete by applying Piaget's principle of primacy of actions. He developed a programming language called LOGO for constructing "microworlds".[6] In this model, an agent, called turtle, could be programmed to follow a few rules like moving forward, turn right, repeat .... In this world, one could construct many mathematical objects by tracing the paths of a moving agent. A single programmable pattern can create polygons to simulated Brownian motion.

His colleague, Marvin Minsky wrote an impactful book with many breakthrough ideas, *The Society of Mind*[4]. He along with Papert initiated agent-oriented thinking in computer science. One of Papert's students, Mitchel Resnick, and Uri Wilensky created a 'macroworld' to create many more microworlds using the multi-agent simulation environments, such as StarLogo and NetLogo. Using multi-agent modeling, we can construct several phenomena as emerging from the actions of multiple agents.[7]

A notable part of this new thinking is to build networks of interacting agents. By a widely well-known model called "preferential attachment" or "rich get richer", several complex natural and social phenomena can be constructed. Such networks exhibit a scale-free character, popularly known as Ziff's law.[1]

What Papert, Minsky, and Resnick have achieved was that they could construct an agent that could construct phenomena. In other words, a new brick of the construction game was invented called an agent. *Give us a multitude of networking agents we can construct every phenomenon of the world.* This may be called the proclamation of the new science of complexity.

6 Conclusion

The history of science can be understood as a series of stories of construction of phenomena, wherein lies the epistemic strength. Both theories and experiments are constructed. Reconstructibility is the hallmark of science. Also, the role of technology, engineering, and mathematics in these construction games is not instrumental but of epistemic nature. Besides, talking about them as STEM games makes it a socially situated rule following cultural practice.

References

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