HOMI BHABHA CENTRE FOR SCIENCE EDUCATION
Tata Institute of Fundamental Research

4th August, 2022

Title: Modeling and sense making

Course Code: SCE316.2

Credits: Two

Period: August - December, 2022

Day and Time: Tuesdays 3-5 pm

Contact hours: 14 Weeks, 14 sessions

Instructor: Mashood K. K.   Tutor: Joseph Salve

About the Course: The course aims to provide an account of modeling and their role in knowledge construction in science, through the lens of cognitive science. In particular we will be discussing processes like idealization, encapsulation, nominalization etc and their relation to sense making. The course will also compare and contrast the artifactual account of modeling with the representational account.

Course Objectives:

- Develop an understanding of modeling from the perspective of cognitive science.
- Develop a cognitive account of the process of idealization.
- Understand the similarities and distinction between representational and artifactual approach to modeling.
- Understand the role of encapsulation, nominalization, and mental simulations and their implications for sense making

Motivation and Rationale:

" The day I went into physics class it was death. A short dark man with a high, lisping voice, named Mr Manzi, stood in front of the class in a tight blue suit holding a little wooden ball. He put the ball on a steep grooved slide and let it run down to the bottom. Then he started talking about let a equal acceleration and let t equal time and suddenly he was scribbling letters and numbers and equals signs all over the blackboard and my mind went dead.

I may have made a straight A in physics, but I was panic-struck. Physics made me sick the whole time I learned it. What I couldn't stand was this shrinking everything into letters and numbers. Instead of leaf shapes and enlarged diagrams of the holes the leaves breathe through and fascinating words like carotene and xanthophyll on the blackboard, there were these hideous, cramped, scorpionlettered formulas in Mr Manzi's special red chalk."

Sylvia Plath in *The Bell Jar*

This is not an isolated anecdotal experience of an individual. One can say with confidence that it holds true for a vast majority of students learning physics, close to 85 % or even more. At the root of this science education debacle is the epistemological poverty of physics education -- students are never given the reason for why it is necessary in physics to `shrink everything into letters and numbers'. Hardly ever are they taught explicitly the processes through which the real world is shrunk and loaded into mathematical symbols and equations. Piles of formulas , symbolic entities and mathematical manipulations are dumped over them, class after class, as if they have signed up for some occult activity in a strange language. The connection between the physics process and the real world, the connection to common sense and the sense making dimension of the process, gets obscured and lost in the suffocating pile of technical jargons and symbols. No wonder they perceive and call equations scorpion lettered entities, and physics as a scary, sickening discipline that puts the mind to death. Among all the classrooms, physics is among the top perpetrators of an ongoing assault on the sense-making capacity of young learners. It would not be far-fetched to say that a silent epistemological violence play out in physics classrooms - strangely for both teachers and students.

The course will be an attempt to go into the cognitive roots of the above discussed problem and draw pedagogical implications. We will discuss how physics as discipline loads reality into mathematics and the role played by idealization and nominalization in the process. The goal is to make explicit some of the key epistemological aspects of knowledge construction in science and thereby thrust forth the fact that whole enterprise is about making sense of the physical world. The pedagogical implication that will be drawn is to recast the pedagogy of physics as an activity in mathematical modeling. We will also discuss accounts of modest success of this approach based on our experience of a series of teacher workshops conducted in Kerala. The implications natural sciences other than physics will also be discussed.

Outline:

Modeling is an important theme in science education research. There exists extensive literature discussing them in the context of learning and instruction. However, theoretical accounts of these phenomena, through the lens of cognitive science and focusing on underlying mechanisms, are sporadic and scattered. It is thus important to make these assumptions explicit and discuss their implications. Discussions based on recent advancements in cognitive science also needs to be brought to the fore to understand the emerging accounts of modeling.

This course aims to discuss the above mentioned concern, by discussing some of the core aspects related to modeling, based on recent insights from cognitive science. In particular, some of the key threads that will be discussed as part of the course are:

1) How is knowledge possible through modeling?

How is knowledge possible is an age old philosophical question and we are far from having a satisfactory, conclusive answer to it. However, science has proven to be a representative of what can be called as reliable knowledge and there is now consensus that all what science does is modeling. This enables us to rephrase the above philosophical question in a more tractable way. This course will discuss processes involved in modeling based on recent insights from cognitive science. Based on our knowledge of how mind functions and interact with the world around, we will explore how modeling results in knowledge generation.

2) A cognitive account of idealization - a key process in modeling and conceptual change

Idealizations are deliberate distortions that generates representational forms of objects, phenomenon and processes, as part of mathematical modeling of the physical world. Often the results of the process gives the impression of a grotesque misrepresentation. However, they have proved to be of inevitable significance in the creation of scientific explanations. As an illustrative example, consider earth, which in reality is a huge, complex object with a molten core, multiple layers of differing density, continents, oceans and mountains. Representing it as a point particle is no less stark a distortion than the `spherical cow'. Yet all the three laws of Kepler and many other insights about motions of planets follows by making use of this idealization. In fact it would not be far fetched to say that idealization as a methodological innovation played a crucial role in the birth of modern science.

How idealization plays a key role in scientific knowledge generation is puzzling and counter intuitive. This course will discuss this from the perspective of cognitive science and explore their role in modeling and conceptual change.

3) Representational Vs artifactual approach to modeling

Representational and artifactual approaches are two ways of making sense of modeling. In the former, the focus is on the relationship between a representation (the final product of the modeling process) and the corresponding target system. Where as the later emphasize on the construction acts involved throughout an extended and dynamic process. This course will discuss various assumptions and the model of mind underlying both of the above mentioned approaches. We will also look into existing accounts of modeling like the one given by Hestenes which claims to be aligned with the artifactual approach but subtly involve elements of the other.

4) Encapsulation, nominalization and mental simulation

Making sense of processes presents a unique challenge, due to their dynamic, online nature. The operational nature of concepts in processes makes it very difficult to view them as a compact self contained whole. The inability to view it as a permanent object on its own may hinder the process of concept development itself. In what may be considered as an idealization as well as concept development and variously known as encapsulation/reification the operational nature of concepts can be transitioned into a structural form. Nominalization may be considered as a form of reification, wherein the operational form in the verb is transitioned into a structural noun form gradually in the process of concept development. We will discuss the relationship between modeling, encapsulation and nominalization.

In addition the course will also explore broadly what it means to understand abstract and conceptually dense entities like equations and the role of mental simulation in the process.

Readings:

1. Nersessian, N. J. (2002). The cognitive basis of model-based reasoning in science. The cognitive basis of science, 133-153.

2. Tall, D., Thomas, M., Davis, G., Gray, E., & Simpson, A. (1999). What is the object of the encapsulation of a process?. *The Journal of Mathematical Behavior* , *18* (2), 223-241.

3. Knuuttila, T., & Boon, M. (2011). How do models give us knowledge? The case of Carnot's ideal heat engine. *European journal for philosophy of science* , *1* (3), 309.

4. McMullin, E. (1985). Galilean idealization. *Studies in History and Philosophy of Science Part A* , *16* (3), 247-273.

5. Sirnoorkar, A., Laverty, J. T., & Bergeron, P. (2022). *Sensemaking and Scientific Modeling: Intertwined processes analyzed in the context of physics problem solving.* arXiv preprint arXiv:2207.03939.

6. Kapon, S., & Schvartzer, M. (2019, January). Nurturing sensemaking of, through, and with a mathematical model. *In Proceedings of the Physics Education Research Conference (PERC (pp. 199-202).*

7. Kuo, E., Hull, M. M., Elby, A., & Gupta, A. (2020). Assessing mathematical sensemaking in physics through calculation-concept crossover. *Physical Review Physics Education Research, 16(2), 020109.*

8. Weisberg, M. (2007). Three kinds of idealization. *The journal of Philosophy* , *104* (12), 639-659.

9. Redish, E. F., & Kuo, E. (2015). Language of physics, language of math: Disciplinary culture and dynamic epistemology. *Science & Education*, *24*(5), 561-590.

10. Lehrer, R., & Schauble, L. (2015). The development of scientific thinking. *Handbook of child psychology and developmental science* , 1-44.

11. De Cock, M. (2022). The educational implications of the relationship between Physics and Mathematics.

12. Boon, M. (2020). The role of disciplinary perspectives in an epistemology of scientific models. *European journal for philosophy of science*, *10*(3), 1-34.

13. Barsalou, L. W., Wilson, C. D., & Hasenkamp, W. (2010). On the vices of nominalization and the virtues of contextualizing. *The mind in context*, 334-360.

14. Barsalou, L. W. (2008). Grounded cognition. *Annual review of psychology*, *59*(1), 617-645.

15. Chandrasekharan, S., & Nersessian, N. J. (2017). Rethinking correspondence: how the process of constructing models leads to discoveries and transfer in the bioengineering sciences. *Synthese* , 1-30.

16. Adúriz-Bravo, A. (2013). A 'semantic'view of scientific models for science education. *Science & Education*, *22*(7), 1593-1611.

17. Nola, R. (2005). Pendula, models, constructivism and reality. Science & Education **13:** 349–377, 2004.

18. Chandrasekharan, S. (2016). Beyond telling: Where new computational media is taking model-based reasoning. In *Model-based reasoning in science and technology* (pp. 471-487). Springer, Cham.

19. Bergen, B. (2015). Embodiment, simulation and meaning. *The Routledge handbook of semantics*, 142-157.

20. Odden, T. O. B., & Russ, R. S. (2018). Sensemaking epistemic game: A model of student sensemaking processes in introductory physics. *Physical Review Physics Education Research*, *14*(2), 020122.

Class Structure and Assessment:

The course will discuss one paper per session. The crediting students will take turns in presenting the paper and leading the discussion. The auditing students can volunteer to present, but is not mandatory. The presentation and discussion have to be structured in such a way that maximum participation from everyone and thereby discussion is enabled.

Assessment is based on the following accounts:

1) Presentation of papers
2) Participation in discussion
3) Two term papers - a mid term and a final term paper. The topic of mid-term paper will be assigned by the instructors and the expected length is around 1500 words. It will have half the weightage in score compared to the final term paper, whose expected length is 3000 -5000 words. For the final term paper students can choose a theme related to modelling or conceptual change, in consultation with the instructor, that is of interest to them.