

Teaching Modeling in Critical Thinking¹

ABSTRACT

Theorists about critical thinking have long argued that a critical thinker must be able to understand the public discourse around scientific reasoning. When we look at how this is implemented in CT Textbooks and standardized tests, however, we find that what counts as scientific reasoning is limited to hypothesis testing or plan success. Modeling, which counts for a up great deal of scientific reasoning, does not appear in any of the standard sources. Participants in this workshop will engage with a demonstration I have developed to teach modeling to inexperienced undergraduates, and brainstorm on possible future materials to be built.

Theorists of critical thinking have long emphasized the importance of teaching scientific reasoning.² However, when this theory is put into practice, the broad range of practices that fall under the category ‘scientific reasoning’ are generally reduced to one or two: hypothesis testing and plan testing. Few standard sources for critical thinking instruction or assessments contain a robust discussion of modeling³ or investigating mechanisms.⁴ This is a shame. Understanding modeling is essential to understanding the public discourse around science today. For example, from June 1st, 2007 to Jan 8th 2008, the word ‘hypothesis’ appears in the science section of the NY Times approximately half

¹ Thanks to my undergraduate students Jan 2008, who helped compile the data presented herein: Devon Brackbill, Lin Sun Oo and Alex Lehmer.

² In one of his often-cited articles (1991), Robert Ennis classifies ‘best explanation inference’ as a kind of induction, and argues that that it is essential to critical thinking. I agree. The Delphi report cites scientific literacy only once, in section 4.1 (‘Querying evidence’, under ‘4.0 Inference’), mentioning, only as an example of critical thinking “To carry out experiments and apply appropriate statistical inference techniques in order to confirm or disconfirm an empirical hypothesis.”

³ By ‘modeling’, I include the process of creating, testing, activating, refining, and breaking models, whether physical, mathematical, mechanistic, biological (‘animal model’, e.g.) or computational (symbolic models in Cog Sci, e.g.).

⁴ Books surveyed include Moore and Parker, 2007, Barry and Rudinow 1990, Waller 1998, Schwarze, Sharon & Lape, Harvey 1997, Epstein, Richard L 2002, Rudinow, Joel & Barry, Vincent E 2004, Paul, R & Elder, L 2006. The exceptions are Munson, Ronald; Conway, David; Black, Andrew. The Elements of Reasoning. Fourth Edition. Thomson Wadsworth, 2004 and Vaughn, Lewis. The Power of Critical Thinking: Effective Reasoning About Ordinary and Extraordinary Claims. Second Edition. Oxford University Press: New York, 2008.

the number of times ‘model’ does.⁵ If we consider the titles alone, the word ‘model’ appears 3 times⁶, and ‘hypothesis’ none.

There are at least two reasons for this mismatch between how we teach scientific reasoning in critical thinking and how scientific reasoning actually occurs.

First, the deductive-nomological model of scientific reasoning, while largely discounted by contemporary philosophers of science⁷ still dominates our thinking about scientific instruction. Critiques of the D-N model are well known and do not need to be rehearsed here. Its continued dominance in pedagogy is probably due to its relationship with the ‘baby logic’ basis of most critical thinking courses and textbooks. Hypothesis testing is little more than a practical instance of *modus tollens*, and hence, easy to explain and teach. The problem with this approach is that deductions to testable hypotheses from universal laws are almost nonexistent in real science, as practiced. And mastery of such concepts will do little to help our students understand contemporary scientific research. For example, what laws underlie the contemporary work in neuroscience – specifically neuroimaging?

Second, and perhaps most importantly, modeling is daunting to assess, either diagnostically and evaluatively. Indeed, even though Ennis includes ‘best explanation inference’ in his taxonomy of critical thinking, he does not provide tools for its assessment. More importantly, the range of activities that count as ‘modeling’ outstrips inference to the best explanation. Modelers seek to establish functional isomorphism

⁵ The study is still in progress. Actual, reliable numbers will be presented at the AAPT.

⁶ ‘Observatory: For Killer Whales, Computer Models Track PCB Levels’ by Harry Fountain, 9/11/2007, ‘From Ozone Success, a Potential Climate Model’, By Andrew C Revkin, 9/18/2007 ‘In Professor’s Model, Diversity = Productivity’, by Claudia Dreifus 1/8/2008.

⁷ The view that science engages in investigating and positing mechanisms and (or through) modeling has been developed by Bechtel and Richardson, Machmer, Craver, & Darden, and Giere, among others.

between the model and the target phenomenon. That functional isomorphism provides the basis for analogical arguments regarding the underlying structure (or mechanism) of the target phenomenon. I know of no CT text that discusses the structure of this reasoning, either in relation to analogical reasoning or scientific reasoning.

I suggest a possible solution. A few years ago, William Bechtel and I developed an interactive flash movie that would allow students to investigate a mechanism using three standard techniques: stimulating, activating and lesioning. ‘Gizmo’ as it became known, is a toy ladybug. It has three inputs (buttons) and three behavioral outputs (tail wiggle, antenna wiggle, legs move). When a student lifts the lid (virtually, of course), he or she discovers three ‘nodes’ in what the students eventually discover is a simple feed-forward neural net. The three inputs connect to two of the three nodes each, and each node is an ‘and’ or an ‘or’ gate. The nodes connect to the behaviors, each of which is an ‘and’ or an ‘or’ gate. The tools given allow the students to record the activity of one node at a time, remove a node from the process, and directly stimulate a node. We then provide a format to build one’s own simple feed-forward network that models Gizmo’s behavior.

The fact that this Gizmo is distributed over the Internet provides us with the advantage that we need to build an assessable pedagogical tool for modeling: we can record which nodes students investigate in what order. There is a long-standing tradition in the sciences of assessing student performance in laboratory settings.⁸ Gizmo allows us to gather and compare performance data on a large number of students without the massive time commitment a lab would require.

⁸ Ennis himself mentions this as one assessment technique for inference to the best explanation tasks in his 1993. As he argues, performance assessment is labor intensive. It is my contention that Gizmo may alleviate some of that load.

Tracking this data will allow us to discover the paths through the problem space followed by most students, providing a basis for assessment of mechanistic investigation. At this point, I would limit such assessment to diagnostic, not evaluative. I plan to run a pilot project with a colleague of mine from Physics this spring, and that data will be made available at the AAPT.

Gizmo is just a prototype. More such interactive materials should be built. In many ways, science instruction, broadly construed, suffers from the same problem: for example, most physicists engage primarily with modeling in their research lives, but teach only hypothesis verification in their classrooms.

Participants in this workshop will experience gizmo first hand. Copies of the program will be available on CD, but Internet access will allow for real-time tracking of decision making of the participants. Second, participants will engage in a discussion, more appropriately perhaps a 'brain-storming' session, on new materials to be constructed, and new techniques for teaching investigating mechanisms and modeling. The workshop should be held in a computer lab, or participants should have laptops with Internet access. I will bring static versions on a CD as a backup.

Ennis, R. (1993) "Critical Thinking Assessment" in *Theory into Practice*, 32 (3)
179-186

Ennis, R. (1991) "Critical Thinking: A Streamlined Conception" *Teaching Philosophy*, 14 (1) 5-24

- Machamer, P, Darden L, and Craver, C (2000) "Thinking about Mechanisms"
Philosophy of Science, 67, pp. 1-25
- Bechtel, W. and Richardson, R. C. (1993). *Discovering complexity:
Decomposition and localization as strategies in scientific research*. Princeton: Princeton
University Press
- Giere, R. (1999) *Science without Laws*. Chicago: University of Chicago Press,
1999

DRAFT