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BOOK REVIEW

# Revisiting Model-Based Learning

## Mark J. Lattery (2017) Deep Learning in Introductory Physics: Exploratory Studies Of Model-Based Reasoning. Information Age Publishing, Charlotte, NC. ISBN: 9781681236292, 286 Pages, $85.99, (Hardcover)

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"How do students learn in a model-centered classroom? What does deep learning in physics mean in this environment?" (p. 247) These are the questions Mark Lattery sets himself to answer in this methodical, careful study of the pedagogical implications of our understanding of model-based science, particularly here in the context of secondary physics education. These questions are central to long-standing and ongoing debates both about the nature and conditions of model-based learning and about the role of models in theory change and conceptual change. On the education side, simply put, the debate is between a coherence view (represented by Stella Vosniadou) and a fragmentation view (represented by Andrea diSessa) of science learning. The former view holds that, for students, learning, much like theory change for scientists, consists in conceptual change. The latter view holds that students only have a fragmented understanding and that conceptual understanding comes at the end of a process that requires bridging beyond these fragments.

However central to Lattery's project this debate is, it is not the book's initial framework. Although *Deep Learning* does not start with a review of the physics education research literature on model-based learning, it is a synthesis of the main debate in this area that it offers. Namely, it arrives at the claim that each approach to model-based learning captures only a part of what it means to achieve a meaningful conceptual understanding of scientific models. Such an understanding requires both addressing prior models from which a student makes sense of phenomena (and why they fail) and grasping new notions that the student can explain and apply in different situations. This view of model-based learning, which is both "regressive and revolutionary," is what Lattery calls "deep learning." This level of learning "is what practicing scientists value and aim for in their own work, and what science educators should value and aim for in the science classroom" (p. 166).

To get there, Lattery starts from the start. Instead of tackling the fragmentation v. coherence debate head on, Lattery first clarifies the terms of the debate. Here, this means asking what a

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model is. To do so, the book takes as its initial framework philosophical insights about the nature of models and the process of model revision in science.

There are few notions in science and philosophy more versatile and ubiquitous than that of model. Lattery briefly surveys perhaps more than is necessary for the purpose of the book (for instance, it is unclear to me that discussing the semantic v. syntactic view of models added much) while leaving some aspects of the working definition of a model, "an imperfect representation of a physical system" (p. 6), unexamined (why imperfect?). However, drawing efficiently from the work of philosophers and historians of science and with illuminating textbook examples such as the billiard-ball model of a gas, he summarizes key aspects of scientific models (pp. 13–19). The model of a target system (for instance, a gas) consists of different models: a *physical* model (an analog, such as a billiard table), an *empirical* model ("mathematical patterns between [experimental] measurements" of variables of interest such as pressure and volume), and a *conceptual* model (a visual model and a lawlike mathematical formula). Each model informs the others. Now, model formation and development consist in synthesizing changing elements from empirical and physical models into a conceptual model, from an initial, fully formed model.

This schematic view of model formation and development as model change is reminiscent of the picture one can find, e.g., in the work of Nancy Nersessian. It offers a framework to assess theory change and model-based understanding. Although the book starts from insights from historians and philosophers of science, it does not aim to advocate a greater rapprochement between disciplines. The initial excursion into philosophy serves to achieve greater conceptual clarity on what models are, so that the question of whether and how non-scientists learn and understand models is better defined.

Chapter 2 takes the discussion into the classroom and describes examples of model-based teaching and learning. The bridging technique "emphasizes the use of physical models, analogical comparisons, and teacher-guided class discussions." (p. 33). It works from an anchor case (an analog) and draws from intuitive, analogical reasoning to understand a target case, with the help of bridging questions as scaffolding. In other words, it starts from the fragments of knowledge students already know about the target model and builds up toward it.

In contrast, the modeling method of instruction (see the work of David Hestenes) works with multiple representations (diagrams, charts, written descriptions, etc.) in a two-step process of model development and model deployment. Models in that context are empirical or data models, which are elicited from simple physical cases and then tested via predictions. The accompanying elicit-and-challenge strategy requires students to defend and articulate their views, which leads to deep conceptual understanding (p. 42). Along with model-based inquiry, these three methods reveal, according to Lattery, the key ingredients of model-centered learning, which are as follows (p. 56):

- Stimulated by a physical thing, event, or process
- Driven by a need to explain how the world works
- Advanced by scientific models and modeling
- Facilitated by peer discourse
- Strongly guided by the instructor
- Acquired by discovery
- Evaluated through the use of multiple representations.

Only after breaking down what models are (Chapter 1) and what model-centered teaching and learning require (Chapter 2) does Lattery introduce (in Chapter 3) the book's central problem and method: does student learning require prior conceptual models? Do students have such prior models, or rather fragmentary notions that are not refined enough to qualify as fully formed models? Should model-centered teaching mainly aim at changing students' prior models or help them form an initial model first? Do students think like scientists (for instance, past scientists) and can they argue their way out of competing models? It is with case studies of student modeling of a vertical ball toss and the motion of a fan cart that Lattery addresses these questions in Part II of the book (Chapters 4–8) before drawing conclusions and examining implications for past and future research (Part III, Chapters 9–12).

The first case study (Chapter 4) finds that a student with no prior formal instruction in the principles of Newtonian mechanics was able to reason in a theoretically motivated way about a physical problem—her inquiry was sophisticated (that is, proceeded from arguments), coherent, and sound. The second case study (Chapter 5) shows that a student with more background knowledge in physics was able to offer five competing models for the same physical problem about motion and inertia—several models with varying interpretations of a pre-Newtonian force decaying after a fan cart is pushed and released. In these first two case studies, the elicit-and-challenge strategy—either between students with a whiteboard or in an intensive interview with the instructor—succeeds in allowing the students to act as creative modelers.

The third case study (Chapter 6) recreates the conditions of student creative model-based reasoning with the aid of simulation software (Modeling Aid) that uses a variety of diagrams and visual and written representations. This tool allows for counterfactual tests and simulations that are well suited to complex model-based reasoning. For Lattery, the level of understanding that the two students in this case study show not only reinforces the findings of the previous case studies, but also allows him to suggest the following key ingredients this setting provided (p. 119):

- Kinematical and dynamical access to the phenomenon,
- Adequate time to think through multiple competing models,
- An opportunity to discuss their ideas thoroughly with peers, and
- A tool specifically designed for model building.

It is in part because other attempts with more students but with the inconsistent use of other model-building tools (namely, without an adequate software) proved unsuccessful that Lattery identifies the above conditions. Although Lattery is deliberately conducting case studies (that is, careful qualitative analysis of a few experiments in order to generate research questions), further test would be needed to support such claims, which he does successfully with a few dozen students in Chapter 8.

Before that, a final case study (Chapter 7) explores the effect of adding a set of increasingly complex bridging activities and follows two students' progress through the comparison of competing models until they reached a "Eureka!"-like understanding of Newtonian forces. This expanded modeling protocol offers the students an additional condition for learning (p. 133):

- The chance to build upon prior knowledge.

The closing chapter of Part II, Chapter 8, replicates these results and draws conclusions about deep learning: the elicit-and-challenge view suggests that students will abandon faulty models when they are challenged, but it is likely to result in an intellectual crisis that will better be overcome with bridging activities, which will provide opportunities for students to acquire or build, from their prior knowledge, the resources necessary to reach the targeted conceptual understanding. Lattery advocates a hybrid view (already suggested by John Clement) of model-centered teaching and learning, in which neither elicit-and-challenge nor bridging is in itself sufficient. He thus characterizes deep learning (on pages 165–166) as what "occurs when the student can explain:

- How and why target ideas and concepts succeed
- How and why initial ideas and concepts fail
- Processes necessary to persuade the modeler from initial to target ideas
- How target ideas apply in new situations."

On that account, deep learning is *both* regressive and revolutionary and requires a *dual* challenge/bridging approach.

Part III reexamines contemporary debates on model-centered learning in light of the case studies of Part II. The most significant part of this discussion is in Chapter 11, "Pathways to formal knowledge," but Lattery introduces it with two preliminary chapters that succinctly but efficiently review debates about the role of the history and philosophy of science for model-centered education (Chapter 9) and research trends in an earlier era of physics education research (about 1970–2000) on the limitations of common diagnostics and instructional materials in mechanics (Chapter 10). Although of interest to this journal's readership, Chapter 9 does little more than summarize key insights on this topic. Lattery adequately and concisely finds historical precedents for the pre-Newtonian models the students in his case studies came up with. In a way that is consistent with the literature on conceptual change, he concludes that deep learning in science "can be characterized as a transformation that pushes old ideas to their limits, and exhausts their defenses, as a condition for adopting more productive ideas" (p. 207). This is true for scientists and for the students featured in this book's case studies. The observation that "a relationship between contemporary and early learners is easily overstated or understated" (p. 207), however, will leave one wanting for more.

Similarly, Chapter 10 briefly reviews how earlier works on student misconceptions and preconceptions from physics education research lacked an account of "how spontaneously acquired student knowledge can be organized into formal scientific knowledge" (p. 226). That is the object of Chapter 11, which cements the book's central claim. There, Lattery revisits more recent debates between the coherence versus fragmentation views. This discussion involves DiSessa's conception of student's "knowledge-in-pieces" consisting of isolated structures (phenomenological primitives or "p-prims"; see p. 228) and which advocates learning with bridging activities. After considering the contrasting view of student learning as mirroring expert model-based reasoning (held by, e.g., James Wandersee and collaborators), this analysis concludes with a compromise position according to which science learning is both regressive and revolutionary; that model-based learning requires both constructing new models from prior ones and consolidating knowledge-in-pieces; and that both elicit-and-challenge and bridging activities are required. As Lattery points out, such a synthesis position is reminiscent of work by Clement.

Each chapter is part of a carefully structured exploratory study and will not easily be read on its own. Any chapter assumes that the reader has read the previous ones, and, for instance, acronyms are not reintroduced even when used several chapters apart. The book's intended audience is the education research community. It is a careful analysis that motivates case studies, which in turn suggest a synthetic view of the nature and implementation of model-centered teaching and learning.

In this book, Lattery does more than reconstruct some main trends in the model-centered learning literature, identify diverging positions, or find support for a compromise view that builds on already existing work. He defines a research program at the confluence of decades of research it builds on. For that reason, it will be most useful to educators and education scholars who are not convinced that model-centered learning requires methods and resources that one usually does not find in a traditional classroom setting.

The detailed case studies will help clarify research and instruction in teacher professional development, by looking past the fragmentation v. coherence debate and by grafting discussions on the nature of models and model change onto pedagogical studies. Because it offers a reframing and a synthesis of model-centered science education research, this work will serve as a reference whose main contribution is to define deep learning both as stemming from our understanding of scientific modeling and as a learning outcome.

Finally, I will emphasize a contribution regarding the role and place of philosophy for education research. Here, while Lattery mines the history and philosophy of science to find insights into how student science learning works (to paraphrase a passage on page 235), he does not aim to advocate a greater presence for the history and philosophy of science in the physics classroom. He does so in a limited and well-motivated way: by simply starting from the observation that models are an important part of science and science education, he surveys works of historians and philosophers of science for conceptual clarification on what such a versatile notion entails, and then pursues pedagogical research whose outcome are insights on what are deep learning and conditions for model-centered education that—to his credit—do not require much prior training in the history and philosophy of science to be beneficial to practitioners.

## Compliance with Ethical Standards

**Conflict of Interest** The author declares no conflict of interest.