Constructing Entities in Scientific Models

Leslie Atkins Elliott, Boise State University, leslieatkins@boisestate.edu
Lauren Barth-Cohen, University of Utah, Lauren.BarthCohen@Utah.edu

Abstract: Science education research on modeling has often overlooked the prevalence of theoretical objects in scientific models. The phenomena being modeled are often not observable (e.g., what causes a ball to move), but theoretical (e.g., what causes kinetic energy to increase); similarly, objects responsible for those phenomena are often not tangible, but theoretical. Supporting students modeling requires support for developing theoretical objects that populate models, and embodied representations may uniquely support the construction of theoretical objects.

Introduction

When one billiard ball strikes another—the first one stopping and the second rolling away—it seems intuitive that the first ball had something that was transferred to the second ball in this interaction. In a model of this interaction, a physicist would say that the first ball had *kinetic energy*, and that *work* transferred that energy from the first ball to the second.

A hallmark of engagement in scientific inquiry is students' pursuit of such coherent, mechanistic models of natural phenomena (Hammer & Van Zee, 2006). An articulation of the construct of *mechanistic* by Russ et al. (2008, p. 512) emphasizes the importance of identifying entities ("the things that play roles in producing the phenomenon"), their properties, and their organization such that they can be said to causally produce the phenomenon being modeled. However, the entities and phenomena that populate most scientific models are not physical objects that are readily noticed, categorized and employed in causal stories, but theoretical objects. In the example above, *energy—a* non-physical object—is positioned as an entity that is transferred by a similarly non-physical entity. Other examples include "*entropy* causes *solubility to rise*," "*genes* cause *transcriptional interference*," and "*topological defects* cause *phase winding*." The construction and shared understanding of such entities represents a significant scientific achievement. Entities in scientific models are not so much physical objects that are readily *identified* as they are theoretical objects that are carefully *constructed* as a significant accomplishment in the development of scientific models.

In this poster, we describe a pedagogical embodied activity used to model energy in systems, Energy Theater (Scherr, et al, 2013). Drawing on video data from students as they engage in this activity, we demonstrate how the embodied nature of the activity supports students in constructing new theoretical entities as part of an iterative process of generating mechanistic models of phenomena. We highlight that such construction of theoretical entities by students is a significant part of modeling. More broadly, this work suggests that explicitly embodied activities may be uniquely powerful in supporting students in such causal, mechanistic reasoning because of the ways in which embodiment supports the construction of entities – a process called nominalization. Finally, we argue that such nominalization supports students not only in using the construct of energy to model phenomena, but in recognizing energy itself as a phenomenon to be modeled.

Background

Below, we begin with a brief overview of nominalization and mechanism, the connections between nominalization and embodiment, and then describe Energy Theater. In our poster, we provide transcripts and related data from classrooms in which high school and university level students use Energy Theater as they construct scientific models.

Nominalization and mechanism

A feature of academic language in general, and scientific language in particular, is the prevalence of *nominalization*, in which "any element or group of elements is made to function as a nominal group in the clause" (Halliday & Matthiessen, 2004, p. 41). For example, if we rephrase *decide* as making a *decision*, "decide" has shifted from a verb to a noun – a nominal group in a clause. Nouns have affordances, as they become objects, and then categories of objects, to reason about and with.

The word "mechanism"—suggesting the interacting parts of a machine—underscores the importance of nominalization in science: we construct nominal groups and then treat them as objects, as if such objects can have a causal - even mechanical - influence on events. Reasoning mechanistically in science, then, usually entails a process of nominalization as we construct theoretical entities; those entities populate our models, and are responsible - causally - for phenomena. Below we will consider how explicit embodiment when modeling phenomena can support students in developing those entities, thus supporting mechanistic reasoning.

Embodied cognition and embodied learning activities

Embodied theories of cognition take the perspective that knowledge representations are fundamentally connected with sensorimotor experiences. Our concepts are largely communicated via metaphors to experiences, such as the saying "there's trouble coming down the road" as if trouble were an object traveling in space. When dealing with abstractions, embodied metaphor is natural, unconscious and pervasive (Lakoff, 1993) and instruction can take advantage of this by engineering experiences that promote certain metaphors.

We anticipate that an explicit embodiment will support students not only in reasoning mechanistically, but in constructing "entities" responsible for phenomena. In science education, for example, students have been successful in understanding new topics with causal mechanisms where the mechanisms account for objects that cause local changes (White, 1993). We now turn to an explicitly embodied learning activity, Energy Theater.

Energy Theater

Energy Theater (ET) is an embodied modeling activity aiming to support learners in understanding energy flows, transfers, and transformations, using a substance model of energy. In this activity, regions of the floor signify objects, and people (students) denote units of energy that move from region to region to represent the flow of energy, and by signaling their form of energy to represent transformations from one form of energy to another (Daane, et al., 2014). Prior research on ET has shown that this activity promotes the disambiguation of matter and energy, distinguishing among energy processes, and representing energy as a conserved. It is not surprising that this embodied activity supports students in using "energy" as a theoretical entity in their models; as we will argue, below, the representation also supports students in constructing other theoretical entities.

Contribution and focus

Our contribution is, first, recognition that defining phenomena to be modeled, and then constructing the entities that populate those models, represent a nontrivial part of scientific modeling. We also argue that employing an explicit embodiment activity when modeling phenomena can support students in developing theoretical entities to populate their model, thus supporting mechanistic reasoning. Our approach is to focus on two settings in which groups of learners are engaged in an embodied modeling activity; in each, their activities promote the development of theoretical objects in a mechanistic model. In the first example in our poster, we demonstrate how this embodied activity supports students in developing a mechanistic model of energy itself. In the latter two examples, we show how using an embodied activity to model physical phenomena leads to the construction of novel theoretical entities in the model (e.g. "regulation," "input," and "output"). These cases illustrate two ways in which the embodiment in ET supports the development of theoretical entities.

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