Title: Mismatches between Represented Science Content and Unmet Expectations as a Mechanism of Model Revision

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Abstract: Models and modeling are a growing topic in science education. We focus on one of the sub-processes of modeling: model revision. The process of model revision is typically underdefined in specially designed modeling curricula. There are many ways to conceptualize model revision, but here we focus on model revision due to mismatches between the science content represented in a model and unmet expectations about that same model. Drawing on the knowledge-in–pieces theoretical framework, we present five cases of such model revision in the context of 9^{th} graders modeling the steady state energy of the Earth using an embodied modeling instructional activity. These mismatches led students to modify both the conceptual content and how it was represented in their model. This mechanism for model revision may be applicable to model revision in other classroom instruction settings.

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1) Subject/Problem

In the new science education standards (Achieve, 2013) there is an emphasis on scientific practices, including use of models and modeling. Within modeling there are a series of short term processes including: constructing models, explaining scientific phenomena with models, critiquing a model, testing a model against ones expectations, and refining a model to improve its explanatory power (e.g. Passmore & Stewart, 2002).

Here we focus on one of these processes: model revision. Model revision is widely viewed as important and has often been built into curricula or instructional approaches (e.g. Buckley et al., 2004; Gobert, 2000; Schwarz & White, 2005; Stewart et al., 1992; Windschitl et al., 2008). It often occurs due to recognition of limitations within existing models, and has often been operationalized as being based on cognitive conflict due to contradictory information (Posner et al., 1982). For instance, in work where children built models for the motion of the elbow, they revised their models based on a failure to adequately capture the accurate range of motion in the elbow (Penner et al., 1997). In that case, model revision was relatively successful and happened through recognition of a limitation in one's existing model.

However, model revision has embedded challenges. For example, Windschitl and Thompson (2006) describe a study in which pre-service teachers were engaged in a model-based inquiry science investigation. In that work, despite scaffolding and a requirement of needing to revise their initial models, the teachers generally did not produce revised models as intended.

Potentially, a more detailed understanding of how and why model revision occurs may provide insights into why it is sometimes more or less successful. Furthermore, this may provide insights into how to better facilitate model revision, specifically how to better design curricula that support model revision beyond simply having model revision be a requirement built into the curricula.

Within model revision it is important not to focus on idiosyncratic changes to a model. One ultimate goal of model revision is improved understanding of relevant science content (Lehrer & Schauble, 2006; Schwarz & White, 2005). Similarly, in our study we focus on revision of the relevant science content and revision in how it is represented in the model, two key aspects of model revision

In our study model revision occurrs on the order of a short time period, often a single utterance. Rather than comparing initial and final models, we are interested in capturing the moments in time when revision occurs; therefore, we use microgenetic analysis as a means to focus on short moments in time (Siegler, 2006). Additionally, given a focus on changes to the science content during a short time period and on how the science content is represented we use a conceptual framework from conceptual change that supports this focus on the science content at a microgenetic level: Knowledge in Pieces (diSessa, 1993).

2) Design/Procedure

Two 9th grade Earth science teachers, Mr. London and Ms. Girard, implemented an embodied modeling activity in their classroom, Energy Theater (ET). ET is a research-based and – validated learning activity based on the substance metaphor for energy transfer and transformations (Scherr et al., 2012). Students act as units of energy (using hand signals to represent the energy form) and create models by moving between regions of the floor that are marked with rope to represent objects in the system. Although this activity is not the focus of the analysis, it is a useful tool for modeling as the rules of the activity are unspecified and students have to work together to choose the objects and energy forms within the system while discussing and negotiating the model.

Neither classroom had previously used ET, but students had completed a unit on the constant temperature of the Earth. Thus, this was not a learning activity in which to discover new ideas, but instead was a modeling activity to represent previously discussed ideas. From the data we observed few obvious challenges with the students understanding of the relevant science content. The teachers assigned the following task: "Model the energy transfer/flow to show how Earth remains at a fairly constant temperature." During two periods (Ms. Girard and Mr. London team taught in parallel, 4 classrooms), we observed a total of six enactments of Energy Theater - for each period, one individual class enactment for each class, followed by a joint enactment, which included all the students from both classes. As an example, a common ET model included the sun being represented by a circular rope on the floor, and the Earth being represented by a second circular rope on the floor. Individuals representing a unit of energy would travel from the sun to the Earth and an equal number would leave the Earth, with the intent of showing the steady state energy of the Earth as people enter and leave it.

These classrooms had the feel of controlled chaos; due to the nature of ET discussion, multiple parallel speakers were common. We focus on moments when only one or a few speakers were talking and the analysis focuses on the entire classroom, not individuals.

3) Findings and Analysis

Conceptual Framework: In our data, classrooms of students generated and revised their model on the order of several minutes during a single classroom activity. There is a perceptual aspect to the data (observing ones own and peers models) and a conceptual dimension (revision of the science content). Thus, our conceptual framework emphasizes both the perceptual and the conceptual. Within Knowledge in Pieces we use coordination class theory (diSessa & Sherin, 1998), which was built to analyze the development and dynamics of knowledge about concepts in science, we analyze student-generated models in terms of the science concepts and how those concepts are represented.

In the analysis we use the following constructs: An observation is known as a *readout*. The observer is literally *reading out* (perceiving) information from the model. Attached to each readout is a meaning or interpretation about the relevant science content captured in that model, known as an *inference*, which links the observed information and the determination of things not easily observable, such as the intended conceptual science meaning. Finally, based on ones own model and prior knowledge, students have *expectations*; these are beliefs about what science content and meaning to represent in models.

Analytically, we identified the moments of model revision from the video and focused on students' questions about their own and peers' ET models. We hypothesized that many questions were rooted in different expectations and inferences despite common readouts, and we coded for *readouts*, *inferences*, and *expectations*. For instance, common readouts included position of people on the floor, the number of people in a location at a time, and the speed of people walking. Inference included interpreting the equal rates of people in and out of the Earth as representing the steady state energy of the Earth. Finally, a common expectation included a belief that the model should include an Earth and a sun. From the coding we document changes in ET models over time and investigate the relationship between those changes and the students' questions.

The analysis focuses on the entire classroom, a similar analysis approach to what is presented in Levrini and diSessa (2007), which also used the same broader theoretical framework but a different context.

Analysis: In the data we found model revision occurring due to two types of mismatches: 1) *inference-expectation mismatches*, which are mismatches between ones intended science content to be represented in a model and another's expectations about that same model, and 2) *inference-inference mismatches*, which are mismatches between ones intended science content to be represented in a model and another's interpretation of what science content is represented in that same model. Here we summarize the five mismatch cases, the first four are inference-expectation mismatches and the last one is an expectation-expectation mismatch.

I: The Earth is not in a steady state because the movement of people isn't regulated. In the first case, Mr. London's class had built a model of the steady state energy of the Earth in which there was no sun and individuals (energy) entered and left the Earth. One member of London's class recognized that the Earth was not in steady state in their model because there was no regulation of when energy entered and left. This was a mismatch between an inference (people in the circle represent energy and the model was not representing the steady state energy of the Earth) and an expectation of the model capturing the Earth's steady state energy. To revise their model one students introduced a mechanism to control when people (energy) entered and left the Earth: tagging.

II: With no sun, where is the energy coming from? Continuing with the previously revised model in which people (energy) left and entered the rope circle (Earth) with a tagging mechanism controlling the movement, in the second case, students in London's class presented that model to Girard's class. Girard's class had expected their peer's model to include a sun and asked a question to this effect: If you have energy on the outside, where is it coming from since you don't have a sun? There was a mismatch between Girard's class inferring that there was no sun in London's class's model and Girard's class expecting their peer's model to have a sun. Girard students critiqued the model, and London's class agreed with this critique and the subsequent joint model contained a sun.

III: "The Earth would freeze" Girard's class generated a model with an Earth and sun. Half of the people (energy) were in each location (object) and simultaneously everyone switched locations, *e.g.*, all of the energy from the Earth went to the sun and vice versa. London's students recognized that during the switch there were momentarily no people (energy) in the Earth, meaning the "Earth would freeze." Thus, there was a mismatch between an inference about the lack of energy in the Earth (when the Earth had no people in it) and an expectation of the Earth's energy being in a steady state. Students from both classes agreed with this critique, and in the joint model there was a tagging mechanism to control when people entered and left the Earth such that the number inside the Earth was constant.

IV: Energy Leaves the Earth and Goes back to the Sun. While Girard students presented the same model as in case 3, London students also commented that all of the people (energy) left the Earth and went directly back to the sun - they expected the energy to go someplace else instead. Girard students accepted this critique, and then another London student applied this critique to their own model (the model presented in case 1). To address this issue, in the joint model the people (energy) that left the Earth did not immediately go back to the sun and instead went outside of the bounds of the model (literally outside the regions on the floor representing the model) before re-entering the model at the sun in order to allow the steady state situation to continue. This revision took into account the material constraints of there being a limited number of people to represent a steady state situation.

V: "There is more of Elijah than there are of us." In London's class from a different period, three people (representing IR, UV and visible light) entered the Earth while one person (representing visible light) left the Earth. This was an inappropriate use of the representation of one person being one unit of energy; in this model the three people entering were intended to represent an equal quantity of energy as the one person leaving. Girard students expected each person to represent an equal amount of energy and commented that the Earth would explode because there were more people entering than leaving. Thus, there was an inference-inference mismatch between how students in London's class intended to illustrate the steady state (focusing on the kinds of energy) and how Girard's class interpreted London's class's model (focusing on the number of people and therefore amount of energy). Subsequently, in the joint model there were an equal number of people entering and leaving the Earth and these people represented energy, not types of light.

Findings: Across five cases of students generating and revising models of the Earth's energy in a steady state, we observed model revision due to mismatches between inferences drawn from the model and expectations of the model. This mechanism drives model revision in terms of changes to both the science content represented within the model and how it is represented.

4) Contribution to the teaching and learning of science

Model revision is widely viewed as important and has often been built into curricula or instructional approaches (e.g. Buckley et al., 2004; Gobert, 2000; Schwarz & White, 2005; Stewart et al., 1992; Windschitl et al., 2008). However, model revision is a short-term process within a larger scientific practice. Model revision needs to be appropriately investigated at a small scale, yet there has been little work capturing how the process of model revision unfolds at a detailed level. Model revision is often assumed to involve conflict or recognition of holes or limitations within existing models, and there are challenges with model revision. An understanding of how model revision occurs may provide insights into how to better design curricula that support model revision beyond simply having model revision be a requirement in the curricula.

We focused on two key aspects of model revision, revision of the relevant science content and revision in how it is represented in the model. Using analytical machinery that facilitates an analysis of both the science content captured in the model and the means of how it represented, we find that particular kinds of mismatches can function as a mechanism for model revision. We used and extended existing machinery from coordination class theory to a new science content area (the steady state energy of the Earth), to a new context (model revision in the context of an embodied modeling environment), and to a new purpose (to model the cognition of a classroom of students).

Using a model of cognition and learning, such as conceptual change in this case, to pursue the details of how the modeling process unfolds is important because it can shed light on fundamental questions about learning within the modeling process and can inform the development of future curricula that involve modeling. The more general mechanism might be applicable to model revision in classroom instruction and may help shed light on how to ensure model revision is successful in classrooms beyond having it be an instructional requirement.

5) How the paper will contribute to the interests of NARST members

This study should be relevant to NARST members as it advances our understanding of an important scientific practice, modeling, and may support the development of future instruction and curricula that aim to facilitate the scientific practices that are emphasized in the new standards.

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