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BOARD # 292: Prospective Elementary Teachers Design Models to Explain Phenomena DUE IUSE

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Prospective Elementary Teachers Design Models to Explain Phenomena IUSE

PROBLEM

Design thinking in scientific modeling promotes creativity, collaboration, and iterative refinement, making it an effective educational tool that enhances critical thinking, problem-solving, and comprehension of complex scientific concepts. Developing and using models, as emphasized by Inkinen et al. (2020), supports students in explaining and predicting phenomena, while frameworks like design thinking make abstract concepts more accessible (Citrohn & Svensson, 2020). The iterative nature of design encourages students to refine models using feedback, explore multiple representations (visual, graphical, or mathematical), and critically evaluate their theoretical and practical soundness, bridging scientific inquiry and engineering practices (Mentzer et al., 2015).

This approach also enhances students' epistemic knowledge, equipping them with skills for hypothesis development, data analysis, and evidence-based reasoning (Lee, 2023). Incorporating argumentation further develops their ability to articulate and critique ideas (Murphy et al., 2018), while aligning modeling activities with meaningful contexts increases motivation and connects molecular phenomena to broader concepts (Dauer et al., 2013). Effective modeling also involves selecting appropriate representations to communicate ideas clearly, with tools like collaborative drawing aiding conceptual refinement (Park et al., 2021). However, modeling remains a cognitively demanding task, requiring students to simplify and structure complex phenomena while navigating representational design (Minkley et al., 2018). Teachers play a key role in supporting this process, creating environments that foster model construction, critique, and revision (Baumfalk et al., 2018).

BACKGROUND

Integrating engineering design into K-12 science education, driven by initiatives such as the Next Generation Science Standards (NGSS) (NRC, 2013), highlights the need to effectively prepare teachers to teach the iterative and flexible nature of design. Research indicates that interventions can enhance teachers' pedagogical self-efficacy in engineering; however, challenges persist, including fostering confidence in students' abilities to succeed (Coppola, 2019). Hands-on, practical experiences in engineering design significantly enhance teachers' efficacy and understanding, as shown in studies where interventions positively impacted preservice teachers' ability to implement engineering concepts in classrooms (Nesmith & Cooper, 2012).

Teachers' understanding of engineering design evolves with experience, shifting from viewing it as rigid steps to appreciating its iterative complexity (Watkins et al., 2020). Their ability to embrace elements like failure as opportunities for redesign can enhance student learning (Tank et al., 2020). Programs emphasizing key design elements and theoretical frameworks, such as Perkins' theory of knowledge as design, can cultivate the creative and systematic thinking required for engineering (Kim et al., 2018). However, more research is needed on how teachers engage in engineering design and develop metarepresentational competence, which is vital for understanding representations in STEM fields (diSessa, 2004).

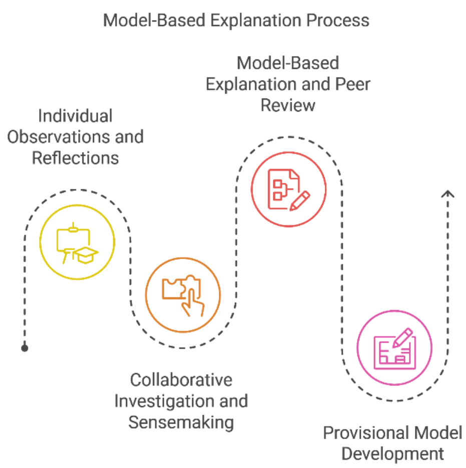
Metarepresentational competence involves creating, critiquing, and understanding principles of representation, which is critical for scientific and engineering literacy. Despite its importance, instruction often neglects broader design strategies for representations. Developing these skills can aid understanding and engage underrepresented students in STEM through creative tasks (diSessa, 2004). Chang (2021) highlights how metavisualization and metacognitive strategies in modeling enhance understanding, offering insights transferable to engineering design. Further research is needed to explore how metarepresentational competence supports teaching and learning in this context.

When teachers have first-hand experience with modeling and design, engaging them in the pedagogy of the science and engineering practices is easier. This kind of preparation prepares them to be better STEM teachers.

RESEARCH DESIGN

Study Context: A Three-Dimensional Approach to Learning Science

A physical science course for future elementary educators used a three-dimensional learning approach, integrating science and engineering practices to develop model-based explanations of observed phenomena (Gouvea & Passmore, 2017; Windschitl et al., 2008).



Structured Modeling Progression

Throughout the semester, preservice elementary teachers (PETs) followed a structured process to model four phenomena:

1. *Observations and Hypothesis:* PETs observed a phenomenon, created drawings of their observations and initial hypotheses, reflected on questions, and developed a driving question for the unit.
2. *Collaborative Sensemaking:* In groups, PETs used whiteboards to represent their understanding, refine their ideas, and discuss scientific concepts (Windschitl & Thompson, 2013).
3. *Model Presentation and Peer Review:* PETs created "exhibition models" to explain the phenomenon, shared them with peers, and refined their work based on feedback focused on reasoning, clarity, and validity.
4. *Provisional Models:* PETs finalized their models and presented them alongside recorded oral explanations, documenting their refined understanding.

Methods and Data Collection

Two sets of three modeling practice tool templates served as data to be analyzed, determining how PETs represented components of phenomena they explained in a model-based explanation. The first phenomenon involved observing a toy train engine moving “autonomously” on a wooden track, prompting the question, "Why does the train engine move back and forth?" The initial unit centered on forces, with investigations into contact forces and forces acting at a distance. The fourth phenomenon involved a ball bouncing on a tuning fork after another tuning fork was struck by a mallet, raising the question, "Why does the ball bounce?" The final unit focused on waves, interconnecting concepts of sound and vibration. In this Work-in-Progress poster, we compare the evolution of representations in two developing models—students’ first and last attempts to model in a physical science course for teachers.

This study, approved by the university's Institutional Review Board office, involved nine prospective elementary teachers from a public institution in the southeastern United States. All participants provided informed consent and completed most of the modeling practice tools. The subsequent analysis examined the changes in the representations generated by these prospective teachers within and across developing models.

Data Analysis

Before commencing rigorous coding, each PET dataset was thoroughly read to gain an overall understanding. This initial reading involved holistic coding (Saldaña, 2015), allowing researchers to record their initial impressions and assign labels to data sections for summarization. In the second coding round, descriptive, pattern, and versus coding (Saldaña, 2015) were employed to identify recurring themes across the data, addressing the research question. The data analysis process aligns with the principles of thematic analysis (Braun & Clark, 2006). Due to the limited space, the findings are presented in a condensed form below.

INITIAL FINDINGS

In this section, we analyze the developmental progression of PETs' modeling through the lens of an exemplary case representing the predominant approach. The analysis begins by examining Carlie's first modeling experience, where they attempted to represent and explain the mechanics of a moving train. Following this, we trace their conceptual evolution through their final modeling task, depicting the complex interactions of a ping-pong ball bouncing on a tuning fork. This comparative examination enables us to observe how Carlie's modeling sophistication and scientific understanding evolved from the initial to the final encounters with scientific modeling.

Carlie's understanding of the train's movement progresses through three stages, evolving from a basic causal explanation to a more detailed mechanistic understanding. Initially, Carlie infers the presence of a hidden magnet as the cause of the train's motion, focusing solely on the "what" without delving into the "how." This initial stage lacks any representation of the causal mechanism (Russ et al., 2008) by which the magnet causes movement.

In the second stage, Carlie incorporates the concept of forces, illustrating the magnet "repelling and then attracting" the train. While this introduces a rudimentary notion of mechanism, the "how" remains largely undefined. The interaction between the magnet and train is still treated as a "black box," with the forces acting as abstract agents.

Finally, Carlie develops a more comprehensive mechanistic explanation in the provisional model. This includes a detailed illustration of the interaction between two magnets with opposite polarities, explicitly showing the magnetic force as the mechanism behind attraction and repulsion. This stage demonstrates a deeper understanding of the "how," moving beyond mere causal identification to a detailed representation of the underlying forces and their effects.

Carlie's understanding transitions from identifying a cause to explaining the mechanism (Russ et al., 2008). The initial emphasis on "what" shifts towards "how," accompanied by increased detail and a move towards greater abstraction. The magnet evolves from a hidden cause to an entity with forces and, ultimately, to an entity with defined magnetic poles.

Carlie's model of the tuning fork phenomenon evolves through three stages, showcasing a progression toward greater detail and sophistication in representing the underlying mechanisms. While identifying key entities such as the mallet, tuning forks, ball, and airwaves, the initial model remains rudimentary. It uses simple lines and shapes, lacks a clear depiction of the structural setup, and relies on implied rather than explicit connections between elements. For instance, the "vibratory waves" seem to float disconnectedly, and the causal link between the vibrating fork and the ball's movement is not visually clear.

The Exhibition Model brings in more detail and labeling. The entities are more clearly defined, and the drawing includes a key for each. However, it still lacks an explicit representation of causal interactions. The focus is on labeling and visually presenting the components rather than illustrating how they interact.

Finally, the Provisional Model adds a crucial layer of mechanistic understanding. Arrows are introduced to show explicitly the action of the waves, the vibration of the forks, and the swinging motion of the ball. This visualizes the transmission of force through the system, providing a clearer picture of how the initial mallet strike leads to the ball's movement. The key in this model is the explicit representation of activities, which further enhances the mechanistic explanation.

Overall, Carlie's progression reveals an increasing ability to represent complex interactions. The initial conceptual sketch gives way to more detailed and specific depictions. The emphasis shifts from merely identifying entities and activities to explicitly showing their connections and spatial relationships. This is accompanied by a growing sophistication in the drawings, moving from basic labels and lines to more pictorial representations. With its explicit depiction of causal interactions, the final model represents a significant step toward a more comprehensive and nuanced understanding of the phenomenon.

This case study examines the development of Carlie's scientific modeling skills through two distinct tasks: explaining the movement of a train and illustrating the interaction of a tuning fork and a ping-pong ball. In both cases, Carlie's models progressed through three stages. Initially, their focus was on identifying the cause of the phenomena with rudimentary visuals and limited mechanistic explanations. The intermediate stage introduced basic forces but lacked detailed representations of their interactions. Finally, Carlie developed sophisticated models that explicitly illustrated the mechanisms at play, including magnetic forces in the train example and the transmission of vibrations in the tuning fork example. This progression demonstrates a clear shift from basic causal reasoning to a more nuanced understanding of underlying mechanisms, reflected in increasingly detailed and explicit visual representations. Carlie’s journey highlights the development of their ability to identify components and illustrate their interactions and spatial relationships, ultimately leading to more complete and scientifically robust explanations.

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