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A Case of Middle Schoolers Reasoning with Multiple Models in Science Learning: Quantitative, Qualitative, or Both?

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Abstract: Most attention on model-based reasoning only explores how students reason either qualitatively or quantitatively. Opportunities to reason about a phenomenon using qualitative models and quantitative modeling have rarely been explored. Yet, scientists require fluid movement between these reasoning structures using models that are qualitative and quantitative. Therefore, this case study examined how middle school students shift back and forth between qualitative and quantitative reasoning through mechanistic and computational models to explain how respiratory diseases spread.

Major issue

Quantitative and qualitative model-based reasoning (MBR) are essential reasoning structures used by scientists, engineers, mathematicians, and computer scientists (Boon, 2011). Qualitative reasoning is defined as "the construction of knowledge models" (Salles & Bredeweg, 2006, pp. 114-115) which focuses on identifying causality and underlying mechanisms and system behavior. Quantitative reasoning is defined as "a way to describe the mental actions of a student who conceives of a mathematical situation, constructs quantities in that situation, and then relates, manipulates, and uses those quantities to make a problem situation coherent" (Weber et al., 2014, p. 25). While science education tends to focus on qualitative MBR and math education tends to focus on quantitative MBR, experts shift between quantitative and qualitative MBR to make sense of phenomena (Boon, 2011), yet there has been little exploration in this area to determine how students navigate this shift when using qualitative and quantitative models to understand phenomena. This is especially relevant as students are tasked with reasoning about socially complex issues spanning science and mathematics, such as a viral epidemic, necessitating both qualitative and quantitative reasoning. We situate our work in this space to ask: How do 7th graders use quantitative and qualitative MBR while engaging with mechanistic and computational models?

Conceptual framework

Mayes et al (2013) proposed a quantitative reasoning framework, encompassing quantification acts (QA), quantitative modeling (QM), and quantitative interpretation (QI). Extending Mayes et al. (2013) ideas for QM and QI, we define QM as developing a model with both quantitative and qualitative attributes, with a further distinction made between mechanistic and computational models. Mechanistic models that students develop, use, evaluate, and revise focus on the components, relationships, and explanatory processes of scientific phenomena. Computational models correspond to a type of modeling where students can construct and modify models using probability to represent uncertain scientific phenomena, and subsequently simulate these models to observe outcomes dynamically (Kazak & Pratt, 2021). QI is defined as the ability to reason across models for trends and patterns to make predictions and construct scientific explanations. As a first step within QI, we recognize that students must notice the salient qualitative and quantitative elements within each model to use for their reasoning and designate these processes as *qualitative noticing* and *quantitative noticing.* Qualitative noticing is how students determine the model's purpose before they use the model to reason about the phenomenon that the model represents. Quantitative noticing is how students interpret what the model shows, such as components and mathematical representations.

Data generation and analysis

This qualitative study, part of a larger NSF project developing a middle school model-based unit on respiratory viral epidemics, focused on a three-day science lesson in a 7th-grade classroom ($n = 26$). The lesson, incorporating both mechanistic and computational modeling, centered around the driving question: "How does the probability of viral infection impact how quickly a virus spreads through a group of people?" Students individually engaged in mechanistic modeling and worked in a small group for computational modeling. Data consisted of video recordings using a Swivl device, student modeling artifacts, and interviews, which were coded to identify instances of qualitative and quantitative reasoning.

Major findings

Overall, we found that students did not separate QM and QI; as they developed the model, they also used and interpreted the model. Our analysis of student discussions throughout the lesson showed that their QM-QI occurred at three different levels (low, medium, and high). Low-level interpreting occurred when students used background information that was explicit within the model structure such as labels, titles, and variables. This reasoning was neither qualitative nor quantitative. Instead, students referenced visible surface information or background knowledge. For example, Kenya said, "[precautions like wearing masks and getting vaccinated] could get rid of it [the disease] completely…because it's like blocking off the disease." Kenya used her background knowledge about viral spread, as opposed to drawing from her mechanistic model or manipulating the computational model. Medium-level interpretations occurred when students used variables within context, made connections among variables and the components of models, and incorporated either qualitative or quantitative noticing. For instance, when Swan was asked about the spread of the virus, he explained, "If someone were to get sick and be in a room with a bunch of people, it [the virus] can spread fast though. Based on how many people there are or like the probability of being sick." Swan qualitatively contextualized his rationale within the realm of viral transmission, moving beyond employing surface knowledge to engage in reasoning. High-level interpretations required using variables within a context, making connections among variables and the components of models, and qualitative and quantitative noticing are interwoven. Jori explained what the data generated with the simulation showed: "They're [the graphs] how many people got infected in that amount of time, period of hours. If there was a 70% chance that it would take less hours. In the 40%, it would take more hours to spread." Jori drew from her experience interacting with the computational model, as shown by her reference to the probabilities used within the model.

Overall, we found that students' reasoning shifted between these levels as they synthesized information across the mechanistic and computational models. The progression of levels (low, medium, high) was not linear, as it depended on the specific knowledge students were seeking to reason from. Students may start at a medium level but shift to a low level depending on the information they seek. When students were asked to synthesize reasoning across the mechanistic and computational models, we found that they variably incorporated both quantitative and qualitative noticing, drawing from both the mechanistic and computational models.

Conclusions and implications

Although progress has been made in understanding how students learn with models (Windschitl et al., 2018), we know little about how students use MBR across different types of models. This study proposes an approach for breaking down MBR into qualitative and quantitative dimensions and emphasizes the need for students to use both qualitative and quantitative MBR in the context of complex real-life issues. It is crucial to further investigate how to best support K-12 students to engage in MBR that is grounded in both qualitative and quantitative reasoning and understand how the use of multiple models can expand MBR. Noticing both qualitative and quantitative dimensions of models is an important first step for students working to shift among different models. More expansive forms of reasoning, such as this coordination between quantitative and qualitative noticing and interpretation, are necessary if we expect students to use the practices of science within their science learning.

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