Understanding Students' Representations of Mechanism through Modeling Complex Aquatic Ecosystems

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Abstract: This study examines how 5th grade students represent the mechanisms of a complex aquatic ecosystem in the Modeling and Evidence Mapping Environment (MEME), a software tool designed to support students in iteratively modeling the elements within a complex system, and their relationships to each other. We explore the various ways students represented mechanisms of an aquatic ecosystem through their models and present our findings on the patterns that emerged and the unexpected ways that mechanisms were utilized within student models.

Keywords: modeling, mechanistic reasoning, science education, complex systems, CSCL

Introduction

Modeling is a difficult practice for young students (Pierson et al., 2017), but is also important in contexts where relationships between elements of a phenomena are unclear, such as in complex systems. An increasing amount of research demonstrates that elementary students can learn and engage with complex systems concepts (Hmelo-Silver & Azevedo, 2006; Danish, 2014; Yoon, Goh, & Park, 2015). When modeling a complex system, it is particularly important for learners to explore and represent the underlying mechanisms rather than just the superficial or surface-level details (Russ et al., 2008).

This study is part of a larger project Scaffolding Explanations and Epistemic Development for Systems (SEEDS), which aims to understand how fifth grade students engage with disparate forms of evidence as they explore complex aquatic ecosystems through modeling. To support these modeling practices, we developed the *Model and Evidence Mapping Environment* (MEME): a software tool that helps students create a simple model of a complex system (Figure 1).

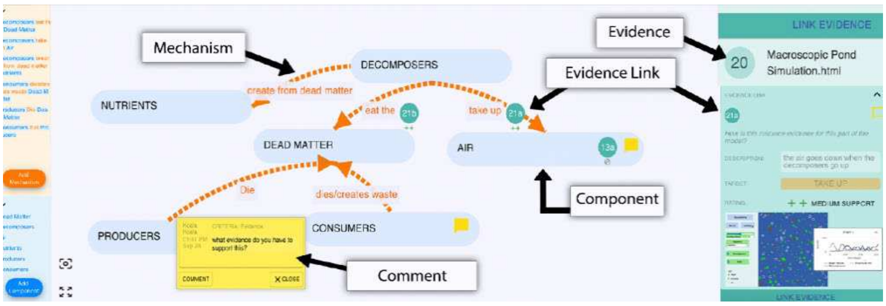

Figure 1: Screenshot of the MEME Software

The aim of this study is to examine how students represent mechanism when modeling complex aquatic ecosystems in MEME. In doing so, we seek to answer the research question: how are students representing mechanisms in different ways within MEME? Are these ways of representing mechanism being recognized and validated by peers?

It has been shown that young students can engage with and develop nuanced understandings of complex systems, such as the water cycle and honeybees working together to obtain nectar (Danish, 2014; Hmelo-Silver et al., 2015). Prior research has shown that the *Phenomenon-Mechanism-Components* (PMC) conceptual framework can aid students in attending to key dimensions of systems as they attempt to model it (Hmelo-Silver et al., 2017). Models that align with the PMC framework explicitly represent complex systems through the combinations of various **components** within a system, and represent the relationships between them through descriptive **mechanisms**, resulting in the **phenomena** being investigated.

Methods

This study was conducted as a five-week long unit with a grade five classroom of 20 students (15 boys and 4 girls consented) at a public elementary school in the U.S.Midwest in the spring of 2020. Students worked in dyads together in the MEME software to iteratively build models and look at evidence. Students also participated in an activity where they reviewed two other groups' models, and left critiques through MEME's commenting feature. While we intended the project to continue past this activity, we were cut short due to the Covid-19 pandemic.

Data for this analysis consists of the final models students completed. We coded students' models in two passes and looked closely at video data capturing the creation of mechanisms in models, and the interactions between peers that produced them. The first pass at coding involved looking at the isolated mechanisms (arrows) of each of the nine final models created in MEME. On this first pass we developed four codes based on Pierson et al.'s (2017) conception of learning progressions of scientific modeling. Our codes were adapted to fit 5th grade students and ranged from 0-3 for the intricacy of mechanism (see Table 1).

Table 1: Table of codes adapted from Pierson et al. (2017) used in analysis.

Code Level	Description
(0)	Mismatch between the mechanisms and components of the model, where the mechanistic explanation could not be interpreted in the context of the model.
(1)	Just an arrow being made to connect to components, with no mechanistic reasoning provided to why they might be connected in the system.
(2)	Some explanation provided for the mechanism but illustrated a vague sense of explaining the relationships beyond the source and target component.
(3)	Representation of a mechanism to explain the underlying relationships of the complex system, often supported by forms of evidence.

In examining the models, we noticed that students often captured robust mechanisms but did so using multiple unlabeled arrows. In looking at the level (1) codes across the models, a pattern emerged wherein students expanded their mechanistic reasoning by combining multiple components connected with unlabeled mechanisms. Therefore, we created two additional codes for a second pass, which we called expanded level (2) mechanisms, and expanded level (3) mechanisms. We unpack how this emerged in the findings below.

We utilized interaction analysis (IA; Jordan & Henderson, 1995) to carefully examine the interactions between peers surrounding the critique of coded level (3) mechanisms, including the expanded level (3) mechanisms. We looked closely at whether students appeared to understand their peers' mechanistic reasoning represented in their models. In these instances, we examined what occurred when the mechanism was understood by critiquing students, as well as what was happening where students failed to recognize their peers' mechanism when coded as level (3). Our results below outline the patterns that emerged in both the creation of mechanisms in modeling, and students' interpretation, or lack thereof, of peers' representations of mechanism across models.

Findings

The results of our coding (Table 2) showed that students ranged in their complexity in representing mechanism across their final models, and that while it appeared that the intricate level (3) codes were sparse on the first pass, they ended up emerging nearly as often in the second pass. Our second round of coding revealed multiple causal mechanisms represented through chains of level (1) codes and components where students conflated mechanisms as components of their models. The most common of these were three interconnected components with two unlabeled mechanisms, where the middle component represented either a level (2) or level (3) mechanism explaining the relationship between the other two components. Our results from the second round of coding found 10 expanded level (2) codes, and 18 expanded level (3) codes across the nine models.

Table 2: Results of the two rounds of coding

Coding Pass	Level 0	Level 1	Level 2	Level 3
1 (Simple Mechanisms)	5	28	29	16
2 (Expanded Mechanisms)	0	0	10	18
Total	5	28	39	34

Across models, level (2) mechanisms tended to be the first connections created by students in their simplified models containing just a few components at the start of the modeling activities (Figure 2). As time went on, level (3) mechanisms began to emerge, but so did many of the level (1) mechanisms of blank arrows. Many of these level (1) components connected chains of components formed the expanded level (3) mechanisms.

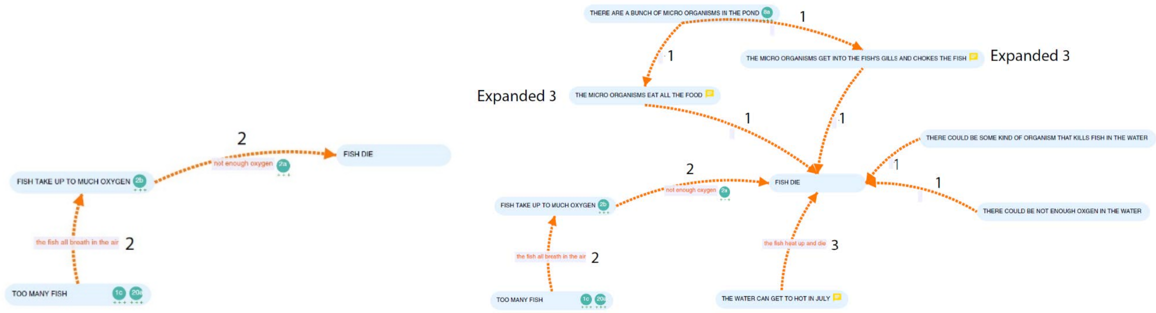

Figure 2. One group's initial (left) and final (right) model pulled from MEME with their mechanisms labeled.

Within interaction students tended to reference their resource library for a specific piece of evidence to support their reasoning before creating a component or mechanism that would end up being coded as a level (3). For example, in the model above (Figure 2), the students looked at one piece of evidence that cited the existence of microorganisms within ponds. They created the component "There are a bunch of microorganisms in the pond" and cited their evidence. The group then created two competing ideas to why the "fish die" because of this. Two additional components were created, "The microorganisms get into the fishs gills and choke the fish" and "The microorganisms eat all the food" and connected to "fish die" through unlabeled mechanisms. These two were coded on the second round as expanded level (3) mechanisms to explain the relationship between the "microorganisms" component and fish dying in the pond. A similar pattern emerges across students' models.

Despite the overall prevalence of level (3) mechanisms within models, they ultimately went unnoticed by peers in their feedback. In the example above, students never commented on any of the level (3) mechanisms, and only ever critiqued expanded level (3) mechanisms as not being labeled. This suggests that student peers may not recognize the representations of high-level mechanisms in scientific models. These instances within and across models reveal that while young students are fully capable of engaging with these complex phenomena, they further scaffolding to productively participate in these expert practices and to help distilling their complex thoughts about systems in precise ways to represent system mechanisms.

Discussion

Our findings revealed that students' models produced unexpected ways in which complex mechanistic reasoning was represented in their models, but ultimately went unnoticed by student peers. These patterns of model construction show that while students' mechanistic reasoning develops along a learning trajectory as they engage with iterating on models of complex systems, they still tend to conflate the concepts of **component** and **mechanism** when engaging in modeling. This may be an indication that students' representations may degrade in clarity as their model and the evidence they work with becomes increasingly complex as they iterate but didn't take the time to refine. Continuing to attend to the ways in which young students represent mechanism in models in ways that their peers can explicitly interpret them, we can further develop scaffolds to promote deep engagement with complex systems concepts for elementary students.

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