Pre-school Children Talking About the Models They Have Constructed: An Analysis of Children Constructed Models and Their Presentation

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Abstract: Despite its proven added value, Modeling-based Learning (MbL) in science is not commonly incorporated into early grades. My purpose in this study was to provide detailed descriptions of the implementation of MbL with a group of 18 pre-K children, engaged in the study of solution of substances in water. The findings suggest that participants could successfully engage in authentic MbL activities, being able to develop a number of different models using prior knowledge and experiences, as well as a variety of features of both analogical and mechanistic reasoning.

Keywords: modeling-based learning, pre-school science education, modeling reasoning

Theoretical framework

Models and modeling are considered integral parts of science learning within the larger context of inquiry-based learning, providing students opportunities to understand and explain natural phenomena (e.g., Justi & Gilbert, 2016). Externalized through various means, a student-generated model becomes a tool enabling students to understand how a phenomenon takes place, and to make predictions about this phenomenon (Schwarz et al., 2009), thus helping them to develop a concrete representation of their understanding of a structure, process, or system, as well as to use that model as a tool for engaging in scientific thinking. Models and the process of modeling are recognized as core components of science education (NGSS Lead States, 2013).

Modeling-based Learning (MbL) has been widely advocated as an approach to meaningfully engage students in authentic practices of learning of and about science (Louca, Zacharia, & Constantinou, 2011; Louca & Zacharia, 2015) and over the years a number of studies have verified its effectiveness. However, these studies have focused mostly on high-school and university students. We know much less about MbL among K-6 students, including detailed descriptions of how young learners work with MbL in science. Further, there is not a unified modeling theory (Ritchey, 2012) that can account for all modeling practices. In this study I am interested in the ways young learners think with their developed models, seeking to describe in detail the MbL discourse and learner's reasoning.

Modeling-based reasoning

Research in modeling-based leaning (MbL) during the past few years has revealed a number of MbL practices that K-6 students follow during MbL (Louca & Zacharia, 2015). Louca et al (2011) have described a framework consisting of three distinct discourse types that learners engaged in: (a) (initial) phenomenological description, (b) operationalization of the physical system's story, and (c) construction of algorithms. They suggest that when students engage in MbL, they work within different modeling discourse types, with different purposes, different end goals and different combinations of MbL practices.

Mechanistic reasoning as an element of modeling-based inquiry

Models as student representations of their understanding of a structure, process, or system in science, are directly related to the representation of causal, coherent explanations of the target phenomenon, that is, causal mechanisms. Russ et al (2008) developed a coding scheme of 7 components of mechanistic reasoning that can be used to identify students' use of mechanistic reasoning. Those components include (i) descriptions of the target phenomenon (what we see happening), (ii) identification of the set-up conditions that are necessary for the phenomenon to happen, (iii) identification of entities (conceptual or real objects that play a particular role in the phenomenon, (iv) identification of the entities activities, (v) identification of the entities properties, (vi) identification of the entities organization, and (vii) chaining (talking about what had happened prior to a phenomenon and what will happen).

Expert mechanistic reasoning also involves the generation, use and evaluation of analogies (May et al, 2006). May et al suggested that students' abilities for analogical reasoning that includes (i) the generation of analogies, (ii) the evaluation of the validity of an analogy and subsequent refinement, (iii) the use of analogies to create new knowledge, and (iv) the use of analogies to communicate ideas in science to others.

Student constructed models
Aligned with other research on modeling-based learning in science (e.g., Gilbert, 1995; Glynn & Duit, 1995; Hestenes, 1997; Ingham & Gilbert, 1991; Penner, 2001), Louca et al's (2011) framework for analyzing student-constructed models of natural phenomena includes five elements of student-constructed models: (i) representation of the phenomenon's physical objects, (ii) representation of the phenomenon's physical entities, (iii) representation of the physical processes, (iv) representation of interactions among physical objects, entities and processes, and (v) the accuracy of the phenomenon depiction. The framework provides a coherent system for analyzing and evaluating student-constructed models based on their structural components, it captures the model's sophistication across the 5 structural components, and it can provide a picture of model progress over time during instruction. This framework can capture differences between initial and final student-constructed models, as well as the differences between the models of different modeling tools.

Purpose
The purpose of this case study is to provide detailed descriptions of how a group of pre-K children describe the models they have developed about how a compound dissolved in water. This is a part of a larger study involving two more modeling case studies (light reflection and plant parts, which we discuss in detail elsewhere (see Louca & Zacharia, 2019). This study is focused on findings on the phenomenon of dissolution, seeking to provide a rich, detailed description of how MbL discourse and reasoning in pre-school education look like.

Methods, data sources and analyses
Following a case study approach (Yin, 1994), this study involved a group of 18 pre-school children (age range: 5-6) working in a STEM education afternoon club. Children met with the author as the instructor of this STEM club once a week for 60 minutes for a total of 7 months. Children in this STEM club investigated a number of physical phenomena, following a number of teaching approaches (investigative-based, problem-based and modeling-based learning). For the purpose of this study, a single case study was selected for analysis, focused on the topic of solution of substances in water, taught through the MbL approach. Three 60-minute lessons were collected, covering a complete investigation of the phenomenon and subsequent development, presentation, and peer evaluation of children's models.

Overview of the unit
Lesson I focused on investigating how different substances behave in water in an attempt to operationally define the phenomenon of dissolution: some substances dissolved in the water (e.g., instant coffee, flour), while others did not (e.g., small rocks, beans). In lesson II children investigated how the phenomenon takes place: In a clear glass of water, we placed a drop of a brown food color at the bottom of the glass. Every 2 minutes, children recorded on a piece of paper what they observed in the glass. After that, within a whole class setting, children observations were displayed on the whiteboard in the sequence recorded and we talked about the changes in the water. Through this discussion, children reached a consensus that by the last drawing, the water became brownish, although it was not as brown as the initial drop of the food color that they had recorded in their first drawing. Then, I asked the following question: "Suppose you are in the water. What would you see happening?" (aka: how does this process take place?). I explained that children needed a description of the story underlying their drawings that could explain how this had happened. Children went back to their group tables and drew their stories on a clear sheet of paper. This drawing was the children's model. In the third lesson children presented their 18 models to the rest of the group, talked about them, and discussed their differences and similarities towards an evaluation of the models constructed.

Analyses
From the videos, I isolated transcripts of student conversations, which served as the primary source of data, specifically focusing on children descriptions and presentations of their constructed models. A total of 165 minutes of children conversations were analyzed. The analysis of children modeling conversations used two complementary approaches for analyzing student conversation. The first analysis on children conversations in science (e.g., Ball, 1993; Gallas, 1995) builds the interest of the science education community in classroom discourse (e.g. Kurth et al., 2002; van Zee et al., 2001). This analysis uses transcribed children conversations as a gateway to children thinking and experience (Edwards & Mercer, 1995). I used discourse to develop detailed accounts of the context and the content of the conversation describing the student contributions towards MbL. My specific focus in this was the children's description of their constructed models. To support this analysis, I also coded the same discourse data using a coding scheme developed in a previous study (Louca, Zacharia, &

Constantinou, 2011), which codes the whole class student talk on an utterance-by-utterance basis, aimed at describing in detail the student MbL discourse in science. Codes included: (a) descriptions of the story of the physical objects or physical system, (b) descriptions of children's experiences in support of those stories, (c) descriptions of physical processes involved (physical object's behaviors), and (d) descriptions of physical entities involved (physical object's characteristics). To support the discourse analyses above, I also analyzed a total of 18 student-constructed models using artifact analysis adopted from Louca et al (2011). Codes from this analysis included the ways that children represented different elements in their models: physical objects, physical entities, physical processes, and physical interactions.

Findings and discussion

Children's models presented and talked about *physical objects* represented in their models (the water, the dye drop, the water and the dye pieces (aka molecules)), *physical entities* (e.g., "pieces" being the smallest possible unit of the substance, the "pieces" having the same color properties as the substance), *physical processes* (molecules moving, each molecule being able to behave independently of the rest of molecules; the random movement of the colored molecules), and *interactions* among physical objects and physical entities. However, only 56% of the children-constructed models had fully represented the various interactions between physical objects, entities and processes; 33% of the models fully included physical entities, whereas the rest of the models had partial representations; 67% of the models had fully represented the physical processes, whereas 11% of the models had limited representations.

Children came up with 5 different models for the dissolving phenomenon, which provided diverse possibilities to explain the phenomenon. One model (5 children) described how a substance in the water becomes bigger and bigger and bigger, gets old, dies and bursts into small "pieces" (aka molecules), which are then spread in the water. In a second model (3 children) children suggested that the substance, like animals, grew up to become bigger, and bigger and bigger, and then it got old, it died, and broke up into small pieces which then swam around in the water turning the water brownish. A third model (2 children) suggested that the substance, like animals, grew up to become bigger, and bigger and bigger, gave birth to their babies (new substances) that they grew bigger and bigger and bigger and then they gave birth and so on. A fourth model (2 children) suggested that the substance in the water infects (like an infectious disease) the water "pieces" (aka molecules) around it (thus water molecules around it turning brown), which in turn infected the water molecules around them, resulting in all the water becoming brown. Lastly, a fifth model suggested that the colored molecules got "stuck" on water molecules, which carried them all around in the water (6 children). Of course, the children's models were not scientifically accurate. However, all 5 models described above were models developed in an effort to provide a story that would explain the phenomenon under study, using a variety of prior experiences that could provide possible explanation(s) about what happens in the phenomenon.

The different student models analyzed used 3 main types of depiction. The first one is a sequential approach, in which children focused on presenting in their paper-and-pencil model a sequence of drawings in an effort to represent sequential scenes of the phenomenon. A second type of model depiction included all these scenes of the phenomenon happening over time in a single drawing. The third type of depiction simply provided the final scene of the phenomenon, with the brown "pieces" randomly distributed in the water. This third type of model did not include or refer to any mechanism of the phenomenon under study.

In their efforts to explain their static paper-and-pencil model while presenting their models, children actively described the story of the physical system and how that occurs using two types of reasoning. Analogical reasoning (May et al, 2006) was used to create links between what happens in the system under study with other known systems. The idea of an explosion, a living organism growing bigger and then dying, and the notion of infectious diseases were used by children to draw analogies of a known phenomenon to an unknown situation. In several instances throughout the data, we observed children to engage in evaluating analogies used in each other's models, in addition to creating or using analogies. Despite the difficulty in constructing models for phenomena of the microcosm, for which is difficult to observe the underlying mechanism, children were observed to use a number of elements of mechanistic reasoning (Russ et al, 2008), such as describing the target phenomenon, identifying entities involved in the phenomena, describing those entities' activities and their properties, clearly viewing their work as developing causal representations of how the particular phenomenon took place. 83% of the children's models were accompanied by mechanistic explanations.

The discourse analysis also revealed that during the presentation and subsequent conversation about their models, children agreed that in order for a model to be an accepted representation of the phenomenon, it had to share 3 important characteristics. (i) The first characteristic was related to the fact that *the model had to be possible*: children thought that a model was accepted if they could feel that it was possible to exist. "Magic" or "fairy tale" -like models were quickly dismissed during the discussion. (ii) A second characteristic was related to the fact that *the model had to be plausible and logical*: that is, the model should be able to provide a tangible and logical description of the mechanism that underlie the phenomenon, in a way that would make sense to the children. (iii) Thirdly, *the model should explain the data collected or observed*: Children felt that acceptable models had to account for the observed phenomenon.

Conclusions

Overall, the purpose of this study was to provide detailed descriptions of classroom-based discourse of MbL with a group of pre-K children, engaged in the study of solution of substances in water. The children in this study were able to engage in MbL, and to develop a number of different models using prior experiences. In this respect, they productively used various features of both analogical and mechanistic reasoning. Findings from this study suggest that, despite the limited experiences with MbL, children in the study were able to engage in MbL, exhibiting abilities to develop and discuss models that can account for their understanding of the phenomenon under study. The analysis data with various coding schemes that account for their developed models and the modeling discourse provided evidence that MbL discourse in these ages can be very rich and productive. Creativity (e.g., 5 different types of models identified and 3 different types of depiction used), along with the use of analogical and mechanistic reasoning seems to become resources for these children to engage in productive MbL discourse.

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