Describing the construction process of models of physical phenomena:
A discourse-based analysis of elementary student modeling conversations

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Abstract
The purpose of this paper was to refine our understanding about how learning in science takes place in approaches that rely on the use of computer-based programming tools for the construction of models of physical phenomena. We analyzed discourse data (student conversations) from six case studies drawn from two elementary science/computer clubs in which students used the Stagecast Creator software to develop models of physical phenomena. In doing so, we seek to provide descriptions of the characteristics of model construction in elementary science education, describe the different types of conversations during the construction of models and the different contexts in which these conversations took place. The findings revealed three types of student discourse during model construction: (a) the (initial) phenomenological description of the targeted physical system, (b) the operationalization of the physical system’s “story”, and (c) the construction of algorithms. Additionally, the findings suggest two different contexts for model construction [(i) the translation of the story of a physical system into programming code and (ii) the evaluation of student-constructed models] that can support productive conversations for constructing models of physical phenomena.

Objectives of the study
The purpose of this study was to identify and describe the characteristics of conversations about science during the construction of models of physical phenomena through computer-based programming. We focused on developing detailed descriptions of how elementary school students constructed models as interpretive representations of physical phenomena through the use of Stagecast Creator (SC - SC is a software designed for young learners, which allows the development of symbolic models/simulations), as well as, on describing in detail from a discourse perspective how the construction of scientific models looks and how different aspects of model construction look in the context of using a computer-based programming tool.

Theoretical framework
Models are systematic simplified representations of physical systems which are used to describe, represent and explain the fundamental mechanisms in nature (Glynn & Duit, 1995). Although such models can be expressed in a number of ways, they are essentially conceptual in nature (Hestenes, 1997; Driver & Oldham, 1986). Science proceeds through the construction and refinement of models, and learning in science entails developing understanding about natural phenomena by constructing models (Constantinou, 1999), as well as learning the process of developing and refining those models (NRC, 1990; White & Frederiksen, 1998).

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One approach to engage students in the practice of constructing and refining models is the model-based learning cycle (MbLC), (Constantinou, 1999). MbLC has two major phases: the model formulation phase, and the model deployment phase. The model formulation phase starts with the need to describe, predict and/or explain a physical phenomenon (first step), which will guide students to investigate the phenomenon and construct a model to represent it (second step). During this phase, students study the physical phenomenon and collect evidence and from the physical world with the explicit purpose to simplify the physical world into physical objects, processes and entities to be represented in a model as a network among those components (Constantinou, 1999; Schecker, 1993; Bell, 1995).

After a model is constructed to what the students consider a satisfactory level, they are ready to go through the second phase of the MbLC, which consists of the deployment of the model in a new situation in order to evaluate the model through a comparison with the real-life phenomenon (Constantinou, 1999; Bell, 1995; Schecker, 1993). The deployment of the model to the new phenomenon leads to predictions as to its properties, its mechanistic behavior and its constituent processes. Comparison between the actual and predicted aspects of the physical system leads to a recognition of the limitations of the model, which can provide feedback for model improvements and additions of new physical objects, processes and/or entities that are part of the physical system studied. Having all this information, students can return back to the model formulation phase, in order to improve or enrich their model. Students will go through the MbLC with testing, revising and re-evaluating the constructed models several times (Bell, 1995), as a process of a step-by-step construction of their model from a simpler to a more advanced level.

Previous studies on modeling-based learning have sought to engage students in using models as tools for representation, exploration, synthesis, prediction and interpretation of physical phenomena, and to provide a learning environment where students can be engaged in the processes of scientific thinking through building, testing, revising and applying models (Papaevripidou, Constantinou & Zacharia, 2006; Schwartz & White, 2005). However, prior research has mostly focused on the student-constructed models as the final products of this process, and researchers has mostly used them as the means for evaluating the gains in both student understanding and reasoning abilities. Therefore, previous studies have thus far failed to provide details about the different steps of modeling-based learning. For instance, what should teachers expect their students to do in an effort to construct a scientific model, and what should they seek to promote or prompt? Additionally, how does the simplification of the natural world into objects, processes and entities take place? Lastly, in what contexts do the learners invent new concepts and in what way do they establish or define them?

This study aimed to contribute towards this direction. Specifically, we analyzed discourse data from six case studies of student modeling focusing on developing detailed descriptions of the different types of conversations that take place during the construction of models (second step of the model formulation phase of the MbLC) and the different contexts that these conversations take place.

**Design and procedure**

This study involved two groups of students (9 and 11 students respectively; 8 fifth and 12 sixth graders) in two metropolitan elementary schools in Cyprus. Students met with the same teacher and the first author once a week for 90 minutes for a total of 7 months. Both groups used Stagecast Creator as the tool for constructing models. For this paper we used data from six case
studies (3 per club) that describe in detail the process of constructing models of particular phenomena.

Videotaped conversations from all cases along with the verbal data from the transcripts served as the primary source of data. From those data, we purposefully selected conversations that took place during the model construction step of the model-formulation phase of the MbLC, aiming to develop detailed descriptions of the process of constructing models of physical phenomena. A total of 810 minutes of student conversations were analyzed. Each utterance was analyzed separately with a focus on the micro-content of the conversation in terms of scientific modeling. For describing the different features of the classroom discourse that happened in the context of constructing scientific models we coded transcripts for references or inferences to three major aspects of scientific models (Michael, Louca & Constantinou, 2006), namely, physical objects (characters), physical entities (object characteristics and object states), and physical processes (relationships among physical objects, their characteristics and their states). Codes for each aspect were developed through open coding (Strauss & Corbin, 1998).

Coding was carried out by the first two authors independently (Cohen’s Kappa = 0.87), and differences in the assigned codes were resolved through discussion. The final list of codes include (1) the description of the story of a physical object or the overall story of a physical system, (2) the description of experiences in support of the above story, (3) the description of physical processes and (4) the description of object characteristics. Coded utterances were displayed in time-line graphs to reveal the temporal interrelationships of the codings. For each case one graph was developed. We then compared graphs from all cases, to identify similarities in the combinations of codes over time.

Findings

Findings revealed three distinct types of discourse that happened in the context of constructing models of physical phenomena with Stagecast Creator. These types of modeling discourse shared similar characteristics (particular combinations of the codes that we used to analyze the discourse data) across all six cases. To make our case, our presentation of findings below follows these three emerging types of modeling discourse describing their characteristics (codes of discourse, content of conversation) and the context in which each type of discourse took place. The three types of model-construction discourse include the (a) (initial) phenomenological description of the target physical system, (b) operationalization of the “story” of the physical system, and (c) construction of algorithms.

Modeling discourse I: (Initial) Phenomenological Description

The first type of modeling discourse involved students describing the story of the overall physical system and/or the story of the individual physical objects involved in the phenomenon under study, trying to establish common grounds for the overall phenomenon under study. When students engaged in this type of discourse, they simply described the story of the physical system under study or the story of individual objects involved in the physical system in a temporal sequence of “scenes” of the phenomenon, supporting their ideas with everyday-life experiences. Everyday experiences were widely used as a tool for reality check, to support students’ ideas about what would happen in the phenomenon under study. Students also tended to evaluate the relevance of proposed experiences with the phenomenon under study, before accepting them as justifying grounds for what would happen in the phenomenon.
This type of conversation usually happened in two different contexts. Firstly, when students started talking about a new phenomenon, they always engaged in this type of discourse; they mostly exchanged ideas about the phenomenon, supporting their ideas with everyday experiences. Secondly, the same kind of discussion was also observed during conversations in which students exchanged ideas about new features that they wanted to include in their models. This discussion followed a discussion in which students evaluated each other’s models based on whether they represented the phenomenon under study in a satisfactory manner.

**Modeling discourse II: Operationalization of the physical system’s story**

The second type of modeling discourse involved students focusing on the description of the physical processes involved in the phenomenon under study (i.e., change in position) or the physical entities involved in the phenomenon (i.e., velocity and acceleration). During this discourse type, descriptions of the overall physical system and references to relevant experiences were limited. Students talked about the physical processes and physical entities involved in the phenomenon in three different ways: conceptually (qualitatively), quantitatively (with numerical examples) or operationally defined. When students talked about a physical process (e.g., the change in velocity over time), or a physical entity (e.g., velocity) in a qualitative manner, they simply described its characteristics without being specific or mathematically precise about those characteristics. When they gave examples about the velocity increase (e.g., indicating that the first second the velocity would be 2, then 4, then 6 and so on), we coded this as talking about the physical entities in a quantitative way and when they gave specifics about the change in the velocity (e.g., the velocity would increase by a factor of two every second or machine cycle) we coded that as operationally defined way of talking about physical processes. During this second type of modeling discourse, students operationally defined the physical processes involved in the phenomenon; however, they did not operationally define the physical entities.

This second type of modeling discourse happened in the context of translating the story of the physical system into programmable code to use in Stagecast Creator in order to develop models of the phenomenon under study. When students agreed on the “story” of the physical system (during the first discourse type), they could move on translating that story into programmable code. Like we encountered elsewhere (Louca & Zacharia, in press), this context required students to take the agreed story and break it down into smaller pieces that could be added through code into their models. References to the overall phenomenon, although rare, were used as a reality check of their proposed model with the everyday phenomenon under study.

**Modeling discourse III: Construction of algorithms**

The third type of modeling discourse included students’ efforts to construct a number of algorithms that would create the model/simulation of the physical system under study, by identifying and operationally defining various interactions in the phenomenon that have causal effects on the phenomenon. To do this, students operationally defined both physical entities and physical processes as interactions among physical entities usually in the context of discussing improvements for their models. Those improvements were specifically focused on adding generalizability power to the models, and the subsequently constructed models were causal representations of the phenomena under study.

The third type of modeling discourse took place in the context of (1) investigating interactions among physical objects, physical processes and physical entities, and translating these
relationships into programming code, or (2) evaluating existing models and proposing changes that could account for more general models of the phenomena under study.

Significance of the study

Overall, these findings can contribute to educators’ understanding of the nature of model-construction discourse in science. We suggest that instead of seeing learning as strictly following a pre-defined activity sequence, science educators may find it more productive to help or “direct” discourse to evolve based on their evaluation of the modeling work and student conversations. In this sense, instead of just providing teachers with a pre-defined sequence of activities for modeling-based learning, an alternative approach might be to provide them also with the knowledge of how different modeling discourses may look like, what are their characteristics, in which context they can take place and in what different ways they can be supportive for scientific modeling.

The ease with which students were able to shift from one model-construction discourse type to another suggests that students have the appropriate abilities to engage in those different conversational types. This suggests that students were able to detect the epistemological differences of the conversation (which are related to the topic of the conversation) and follow the new epistemological mode of the conversation. This implies that teaching should in part relay on what students bring into the science classroom – both experiences and epistemological knowledge – in ways that can be further supportive for further developing i.e., abilities to differentiate between different discourse types or follow epistemologically different discussions (Louca & Hammer, submitted).

A final implication concerns the role of the use of programming as a modeling tool in science. As we highlighted above, the computer media used in the study seemed to contribute to the context that triggered changes in the model construction discourse types that we reported in this study. Starting the study of a new phenomenon, or considering new features to add to an existing model, puts students into the first modeling discourse type. The context of translating the overall story of the physical system into code, lead students into the second discourse type. Trying to add generalizability power to their model, and the subsequent need to invent and use variables as representations of object characteristics, lead students into the third type of discourse.

References


