Modeling Practices as a Function of Task Structure

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Abstract:
To reason about complex natural systems, learners need opportunities to develop and represent their ideas about how these systems operate. In our work, we use an explicit conceptual representation – the Structure-Behavior-Function (SBF) ontology (Goel et al., 1996; Hmelo-Silver et al., 2007; Goel et al. 2009) – to help middle school students model and organize ideas about a one such system, the aquarium ecosystem. Our learning environment embeds SBF thinking in technology including simulations, digital modeling environments, and hypermedia (Hmelo-Silver et al., 2008). These tools allow students to formulate, test, refine, and repair their mental models of the system dynamically. In particular, we report on one aspect of this work which focuses on the second theme of the symposium, the development and study of tools to support students in working with models. In this paper, we present data on how three different teachers used the same tool to achieve their learning goals through different task structures. Further, we provide an analysis of student-generated models from each of these classrooms based on an SBF coding scheme to gain a better understanding the type of knowledge that students are representing through modeling practices. We provide evidence on how making the SBF representation scheme explicit can foster student representations that go beyond the structural representation (the "what") of a system and include articulations that provide dynamic and procedural aspects (the "how" and "why").

Introduction:
Engaging in modeling activities allows students to develop and refine scientific explanations. Such scientific practices should be included as an essential component of the science classroom experience (Duschl & Grandy, 2008). Although models are an essential part of scientific inquiry, teachers often employ models as a way to directly communicate existing knowledge (Van Driel, et al., 1999; Teagust, 2002) rather than guiding inquiry to develop deep understanding of scientific phenomena. When models are used simply as static representations, students are rarely given the opportunity to use these representations for analysis, prediction or to understand reasons that underlie dynamic processes (Carey & Smith, 1993; Van Driel & Verloop, 1999).

Computer simulations provide an excellent context in which students can engage in modeling (Clement 2002). These opportunities are especially important when teaching about complex systems because they provide a way in which students can represent multiple levels of abstraction and shape ideas which represent different temporal and spatial scales simultaneously (Hmelo et al., 2001, Hmelo, Nagarajan, & Day, 2000). Understanding abstraction across different dimensions, although critical for scientific inquiry, is not easily fostered through the use of static tools, such as text books and physical models common to many science classrooms.

Even when provided with such technology-based interventions, classroom enactments are largely dependent on teacher understanding of the tools being used to test ideas (e.g., Justi and Van Driel 2005) and of technology as a scaffold (Leinhardt & Steele, 2005). Although computer based modeling is largely mediated by student groups, the teacher is important in setting classroom norms (Webb et al., 2006). For example when Puntambekar, Stylianou, & Goldstein (2007) studied teacher enactment of new technology in the classroom, they found significant differences in learning gains that can be related to differing teacher practices in areas beyond the use of the tool. Further, Gray et al. (2008) found that two teachers although given very similar tools, enacted two very different classrooms based on different views of computers, simulations, and classroom inquiry.

Although these studies support the notion that classroom culture and technology tool use is greatly affected by the teacher, questions regarding to what extent learning gains can be attributed to the modeling task independent of varying teacher practices still remains to be determined. In this study, we address this question using data from three middle school science classrooms. In particular, three teachers participated in similar training and were given access to the same computer-based modeling package that had embedded a particular ontology for understanding complex systems. We will first describe this ontology and the modeling package. Next we will address the different classroom enactments and task structures. Finally, we will conclude with an analysis of student-generated models and the associated gains in learning.

Structure-Behavior-Function (SBF) Ontology and Computer Simulation:

The Structure-Behavior-Function (SBF) ontology (Chandrasekaran et al. 1993) encourages individuals to explicitly represent a system by its structures (i.e., what are the parts?), its behaviors (i.e., how do the parts do what they do?) and its functions (i.e., what do these parts do?). Evidence suggests that this ontology enables richer student explanations about complex systems (Hmelo-Silver et al., 2007; Goel et al. 1996). Further, the use of computer simulations paired with direct SBF instruction, has resulted in significant learning gains in the three classrooms in which this study takes place (Hmelo-Silver et al., unpublished data).

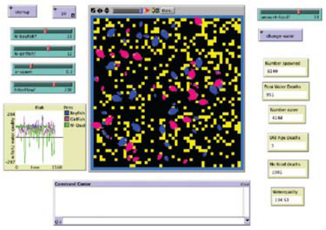
In our study, SBF is scaffolded through the use of the Aquarium Construction Toolkit (ACT). ACT combines an electronic journal, a modeling interface in which students are able to represent biotic and abiotic structures and the functional and behavioral relations between these structures, and tables for data collection and analysis. In addition, ACT links to the RepTools for Aquaria Toolkit (Hmelo-Silver et al., 2007). RepTools was designed to accompany a physical aquarium installed in each classroom. The kit provides digital tools which feature a function-centered hypermedia from which students can read about the structures, behaviors, and functions occurring within an aquarium system and includes a micro and macro-level NetLogo based simulation. The macro-level simulation enables students to test ideas about fish spawning and water quality and the micro-level simulation enables testing of ideas about the nitrification process that occurs within an aquarium as part of its biological filtration. In combination, these digital tools allow students to not only test ideas about a model complex system (i.e., the aquarium) but also to explain processes and outcomes that occur at multiple levels within the aquarium. Figure 1 provides snapshots of the user interface for this suite of tools.

Classroom enactment and task structure:

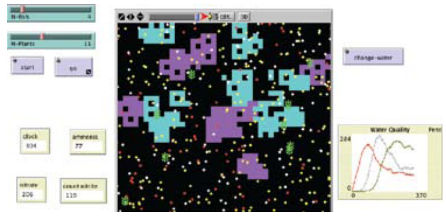
We report an analysis of models generated by the modeling function of the ACT tool. These models were generated by 189 middle school students from three public schools who volunteered to take part in this study. These students were either 7th grade life science students or 8th grade physical science students. Although the study was conducted as part of students' science instruction, none of the three classrooms had aquaria or SBF taught prior to the intervention. In all classroom settings, the teachers used the RepTools and ACT toolkits to help students learn about the aquarium system. One month prior to the study, all classrooms had a physical aquarium placed in the classroom. Students used the digital tools on laptops while working in small groups, which varied from 2 to 6 students per computer, in every class to generate fifty models for analysis in this study. All teachers attended an evening workshop where they were introduced to these digital tools prior to implementation in the classroom.

Figure 1: Screen shots from A. Net logo (macro-level simulation), B. NetLogo (micro-level simulation), C. Hypermedia and D. Modeling interface.

A.

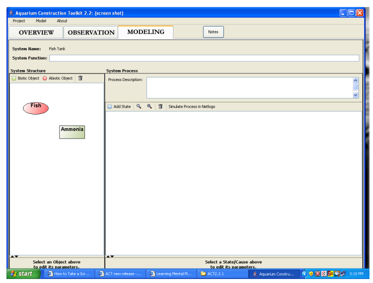


B.



C.

D.



Below we characterize the way in which each of the three teachers used the tool in their classrooms. Although the research team was in each classroom for the duration of the project for data collection and to provide technical support, teachers were not directed in any manner beyond explanation of SBF and tool capability. This freedom allowed teachers to incorporate the technological tools in a manner they saw as appropriate and presumably one that complemented their pedagogical style.

Teacher A

Teacher A began with a discussion of Structure-Behavior-Function and how using this type of thinking strategy can help to reason about complex systems. She then introduced the classroom aquarium as a complex system. Students then had the opportunity to read through the function-centered hypermedia. Next students worked first with the macro-level fish spawn simulation and then with the micro-level nitrification process simulation. Following this, students were instructed to generate a model of the nitrification process based on the simulations they had run and through consultation with the hypermedia.

Teacher B

Teacher B also began with a discussion of Structure-Behavior-Function but then had students use the ontology as a means to model the aquarium installed in the classroom. Students did not have the opportunity to read the hypermedia until after the naïve models were generated. Following this, students were able to explore the hypermedia and both simulations. Once completed, students refined their models and incorporated new knowledge as they collected it through self-guided inquiry.

Teacher C

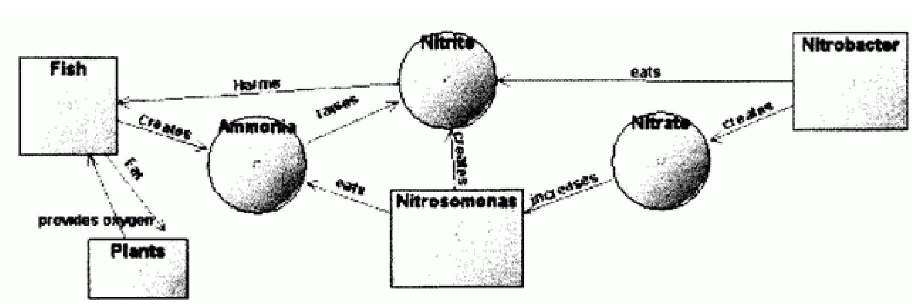
Teacher C began with a discussion of the aquarium and used this as a context to introduce Structure-Behavior-Function thinking. Students were immediately able to read through the hypermedia and answered a series of guiding questions provided on a worksheet. Students also had worksheets on which questions about the macro-level and then the micro-level simulation were provided. Students completed these tasks immediately after working through the hypermedia. From there, students were asked to model the entire aquarium system.

Each teacher used a different approach to introduce both the aquaria and SBF thinking; thus the modeling task was also differently implemented based on classroom culture. Teachers A and B first introduced SBF and then encouraged the modeling of the aquarium whereas Teacher C chose to introduce ideas in the reverse order. Teachers A and C used the model as a means to represent ideas in summative fashion, whereas Teacher B chose to use the modeling task throughout implementation as a means to continually formulate and refine ideas. Additionally, Teachers B and C chose to have students model the entire system while Teacher A had students generate a model based on a portion of the system that corresponded quite closely to one of the simulations. Finally, although all teachers explicitly introduced SBF to the students as a way to organize their learning about the complex system, the emphasis and duration of the exposure to the ontology varied significantly by teacher. In sum, these differences in teaching practices and focus resulted distinct models produced by the students in each classroom (Figure 2).

Figure 2: Examples of models from Teacher A, Teacher B, and Teacher C based on appropriated modeling task.

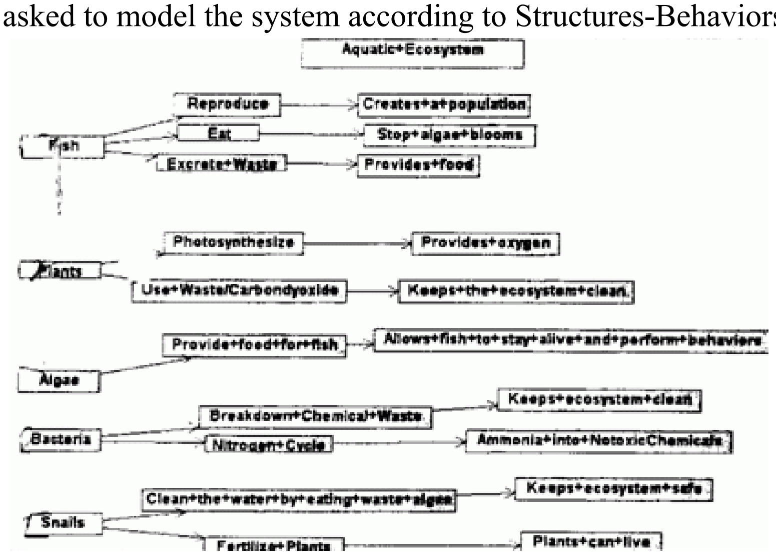
Teacher A:

Students were asked to model only the nitrification process; as a subsystem of the aquarium:

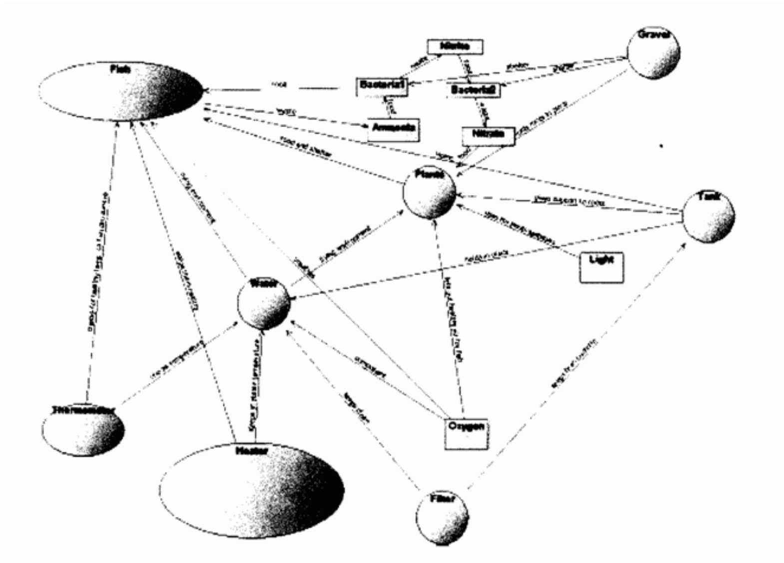


Teacher B:

Students were asked to model the system according to Structures-Behaviors-Functions:



Teacher C:
Students were first introduced to the aquarium system and then asked to model the elements and their relationships.

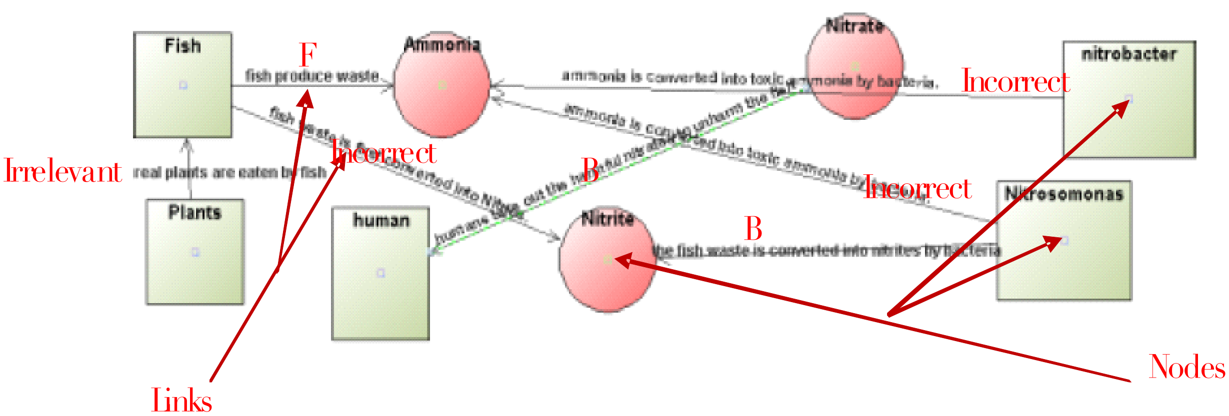


Model Analysis:

Frequency Model Coding. Models were analyzed as a representation of student learning. Specifically, we sought to determine to what extent students represented structures, behaviors, and functions as a reflection of their holistic understanding of the system. Models for every class were coded in several ways in order to elucidate differences in the models developed between classes. Model analysis began by (1) counting structures (nodes), counting links (relationships between nodes), averaging links to nodes, (2) determining nodes with multiple links, and (3) coding micro and macro-level aspects modeled. We began by assessing the number of links, and nodes then averaging the number of links per node. These counts allowed us to determine the number of relationships students report for each structure in the aquarium system (i.e., nodes) as well as the number of relations to that structure (i.e., behaviors or functions). Second, through this simple count, we also determined what, if any, structure served as a central element within the system (i.e., the structure that might be related to all behaviors or functions in the tank). Finally, structure frequencies on both the micro- or macro-level were also determined to evaluate whether students were indicating that system operation occurs on multiple spatial scales, something that students in our past research have had difficulty with (Jordan et al. in press).

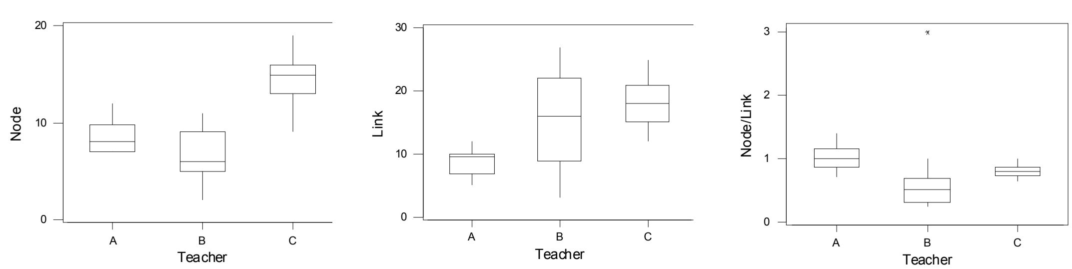
Expert Rating and Behavior and Function Relationship Coding. In addition to the frequency counts (i.e. number of nodes, number of links), we wanted to determine to what extent students' ideas were valid as rated by an expert and determine the type of understanding represented in student models (i.e. articulating the "how" and "why" of the system). To do this, the nature of the relationships between nodes and links (i.e., behaviors or functions) were coded using an expert-level model as the criterion for sophistication (i.e., level of complexity). Further, two experts on the system being modeled were asked to rate models based on their own criteria across the three teacher groups. An example of model coding is shown in Figure 3. In this example, the squares represent biotic structures and the circles abiotic structures. Model analysis began with a count of nodes (8) and links (7). Each link represents a relation, which is coded as a behavior, function, or invalid (i.e., irrelevant or incorrect). The ratio of nodes to links determines the ratio of structures to relations (1.14). An example of an incorrect relation: *ammonia is converted into toxic ammonia by bacteria* and an irrelevant link: *real plants are eaten by fish* (because the nature of the food is not relevant and there are no real plants in the system in which the student is modeling). In this model there are eight structures, two behaviors (*humans take out the harmful nitrates* and *the fish waste is converted into nitrites by bacteria*) and one function (*fish produce waste*). This coding was then averaged by class for comparison.

Figure 3. Example of SBF Coding Scheme applied to student model.



Results: The numbers of nodes, links, and nodes/link are show in figure 4. Given the differences in modeled phenomena and modeling tasks, it is not a surprise that coding results varied since typical model in each class varied. Overall, students in each of the three classes depicted different numbers of nodes and links- which would be expected for Teacher A (given the task of representing just the subsystem of the nitrogen cycle) but not between Teachers B and C (given that both teachers modeled the entire aquarium). Specifically, students in Teacher C's class represented considerably more structures (nodes) than the other two classes. Frequency of links, however showed greater variation with Teacher A showing the least, and Teacher B and C having comparable results on average, however, with considerable spread between models for Teacher B. Finally, node/link averaging shows that Teacher A's students on average have a one-to-one relationship between structures and the links. Teacher C's students have only slightly more links with very little variation, and Teacher B's class models had on average about twice as many links to structures.

Figure 4. Box plots with data for nodes, links, and nodes per link. The horizontal lines represent the median value, while 50% of the data fall in the box. The span of the vertical lines represents data spread.



Structures of Influence. Additionally, models were coded to elucidate structures within the system that posses a disproportionate number of links per single node. Teacher A's models showed micro-level elements as central most-likely given the micro-scale nature of the nitrogen cycle. Teacher B's models tended have no centrality given the nature of his modeling task that had students look at the effect on function of the individual structures. Teacher C's models, however, showed a clear tendency to represent most structures in the tank and to have a relationship to the water, fish and the tank.

Micro and Macro-level Representation. Students from each class also represented different levels of micro-to-macro level processes and central elements. Teacher A's students clearly represented more micro-level phenomena which is not surprising given that a strongly micro-level element of the system is being modeled. The means by which Teachers A and C's students drew their models lead to central elements being depicted. Teacher A's students, however, drew a large number of irrelevant concepts. The reasons why this might be so is unclear, but these students tended to depict more behaviors when compared to functions. The micro level simulation might better facilitate identification of behavior.

Expert Model Rating. To establish a criterion by which models could be evaluated, we asked two aquarium experts who were each graduate-level students and who have each published papers on the aquarium system. The models for each class were ranked differently be each expert. Expert A rated the models based on the complexity of the system being represented. Complexity is determined by the entirety and the validity of the connections. Teacher C's class models were highly complex with a high level of behaviors and functions being represented. These models also tended to have relevant links. Teacher B's students, however, largely did not explain the links or the nature of the connections. Teacher A's students fell in between. Expert B, however, tended to rate the sophistication of the biological phenomenon being discussed. With this, Teacher B's students tended to discuss ecosystem-level phenomena. Teacher A's models appeared to be more elemental, with Teacher C's models falling in between. Thus, the expert raters helped differentiate the affordances of the different modeling tasks.

Table 1. Averages of coded responses from each teacher's models. Experts rated the best models as 1 being the best.

Teacher	Average % of Micro-level	Average % Irrelevant/Relevant	Average # of Behaviors (SD)	Average # of Functions (SD)	Expert Rating A	Expert Rating B
A	56.6	65	2.25 (2.49)	1.88 (1.13)	2	3
B	28.2	18	7.06 (4.35)	8.24 (4.83)	3	1
C	37.3	20	5.60 (3.05)	8.45 (4.75)	1	2

Discussion:

It comes to no surprise that teacher appropriation of the modeling task resulted in different classroom products. What is interesting, however, is the different learning outcomes associated with slight differences in modeling activities, since all teachers were equipped with the same tools and subject matter for modeling and ontology for organizing their students' learning.

When inspecting the models, one of the most obvious differences comes from Teacher B's class. Here students are explicitly representing elements of the SBF ontology by putting primary focus on the elements (i.e., boxes). In doing so, it appears that students were able to represent complex ideas in terms of the biology of the system as pointed out by one of our experts. There might, however, exist a tradeoff because students failed to articulate the same number of relations when compared to the other two classes (i.e., roughly half when relativized for the number of nodes). This lack of connectivity was seen as being less sophisticated when depicting ideas about the entire system, as suggested by our other expert.

Another key difference between the classrooms is the level to which the modeling task was specified. In one classroom, students were asked to focus on a single section of the system. This group was the only one to specify more behaviors than functions. This view is mechanism-versus-outcome oriented (i.e., the "how" of the relations versus the "why" of the relations). Again, this might represent a tradeoff between understanding the processes embedded within a system versus the outcomes or implications of these processes. It may be that an explicit focus on the micro level of the system helps makes the processes more salient.

We did, however, find some commonalities in spite of differences in task appropriation. The modeling tool and associated instruction in all three classrooms resulted in students communicating mechanistic and abstract ideas. This is in contrast to pictorial replicas of the tank and encourages students to move beyond static ideas. In a previous study in which similar students were asked to model aquaria, we found that, when asked to model a fish tank without the SBF scaffolding and associated model interface, students, even though they had access to the hypermedia and the simulations, drew pictures of mostly macro-level structures (Jordan et al. in press). We suggest that it is the Structure-Behavior-Function ontology combined with the digital tools that provided students with a framework by which dynamic ideas can be fostered and refined. The SBF ontology helps provide a conceptual representation that makes what needs to be included in the model explicit. Our results suggest that there are multiple paths to productively engaging students in the modeling practices of science.

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