REPTOOLS: REPRESENTATIONAL TOOLS TO SUPPORTING LEARNING ABOUT COMPLEX SYSTEMS

Abstract: Understanding complex systems is critical for becoming scientifically literate citizens. Examples of complex systems range from ecosystems to car engines. To learn about complex systems, students need experiences that engage them with complex systems phenomena. In this paper, we report on a classroom study that provides these kinds of experiences using a representational toolkit, RepTools. In particular, we focus on providing experiences with an aquarium ecosystem using RepTools as part of an inquiry curriculum that integrates hypermedia, a physical aquarium, and multiple computer simulations. The preliminary data analyses indicate the promising effects of the RepTools in supporting deep learning about complex systems and improving the teaching and learning of science. The conceptual representations embedded in the toolkit affected what students learned, as shown by the large gains particularly in the behavioral and functional aspects of the system. The visualization and manipulative opportunities provided by the NetLogo simulations afford students an opportunity to test and refine their hypotheses, which may lead to deeper understanding of complex systems.

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Understanding complex systems is critical for becoming scientifically literate citizens (Sabelli, 2006). Complex systems are composed of multiple interacting levels with heterogeneous components and their aggregate behavior is greater than the sum of the parts (Hmelo-Silver & Azevedo, 2006). Examples of complex systems range from ecosystems to car engines. To learn about complex systems, students need experiences that engage them with complex systems phenomena (Jacobson & Wilensky, 2006). In this paper, we report on a classroom study that provides these kinds of experiences using a representational toolkit, RepTools. In particular, we focus on providing experience with an aquarium ecosystem using RepTools as part of an inquiry curriculum that integrates hypermedia, a physical aquarium, and multiple computer simulations.

Theoretical Framework

External representational tools can be powerful tools for science education by supporting the construction of cognitive representations. Software-based external representations can be used to guide students' thinking and support collaborative knowledge construction (Suthers & Hundhausen, 2003; Toth, Suthers, & Lesgold, 2002). Such representations can serve as cultural tools that enable sophisticated ways of thinking (Tabak & Baumgartner, 2004). In this research we examine the effects of external representational tools (such as hypermedia and computer simulations) on how students learn to use a cultural tool that is a conceptual representation (structure-behavior-function [SBF] reasoning).

Experts use SBF representations to reason about complex systems (Hmelo-Silver & Pfeffer, 2004). Structure refers to the "what" or the parts of the system. Behaviors refer to the "how, " the mechanisms that enable structures to achieve their function. Functions focus on the aspects of the system relating to how particular components enable overall system function. Previous research showed that using a functional representation to organize hypermedia about a complex system enhanced student learning compared with hypermedia organized around the structures (Liu, Marathe, & Hmelo-Silver, 2005). We used the SBF representation to design function-centered hypermedia that would introduce the complex system ideas about the aquarium ecosystem. By exploring the hypermedia, the students obtained basic knowledge about the system, and the underlying conceptual representation can help students organize knowledge in an efficient way as experts do.

Previous research has demonstrated that complex systems are difficult to learn because they exhibit emergence, in other words, the behaviors of the constituent structures affect the aggregate behavior of the system through local interactions (Jacobson & Wilensky, 2006; Wilensky & Reisman, 2006). Many of these interactions are invisible and dynamic, which also serves to increase comprehension difficulty (Feltovich, Coulson, & Spiro, 2001). Thus a deep understanding of a complex system requires perceiving the relations among components in the system, particularly among different levels such as structure and function. Unfortunately, students tend to ignore the important relations because they cannot be seen.

Computer-based simulations can provide opportunities to support student learning about complex systems by making the interacting behaviors and functions visible. This allows students to test and modify their ideas about such systems based on the dynamic feedback provided by running the simulation models (Hmelo, Holton, & Kolodner, 2000; Wilensky & Reisman, 2006). There are two important ways that computer simulations support understanding. Firstly, simulations draw students' attention to system dynamics so that they have the opportunity to observe the effect of one component on other components in the system, which is difficult to accomplish in static media. Secondly, the computer simulations provide representational tools with which students can negotiate, compare, and repair understandings to achieve convergent conceptual change (Roschelle, 1996). For instance, students can share and negotiate individual ideas and strategies in order to reach a desired result in the simulated context, for instance, to reach a chemical balance in the aquarium so that fish can live. In our current study, we designed two simulations in the NetLogo environment.

RepTools

The RepTools toolkit includes a function-oriented hypermedia and two NetLogo (Wilensky & Reisman, 2006) computer simulation models. The hypermedia introduces the aquarium system with a focus on the functional aspects but provides linkages between the structural, behavioral and functional levels of aquariums. By exploring this hypermedia, students can construct a basic understanding of the system to prepare them for their inquiry activities with the simulations. The hypermedia can also be available as a reference to help students interpret the simulations. The function-oriented hypermedia introduces students to this system with two big functional and behavioral questions on the opening screen: "Why is it necessary to maintain a healthy aquarium?" and "Why do fish and other living things have different roles in the aquarium?" By clicking on these questions, the students can go to information about the functional aspects of the system, then to the behavioral aspects and finally to the structural knowledge (see Liu et al, 2005 for more details).

We also designed two NetLogo simulations – the fish spawn model and the nitrogen cycle model – presenting models of aquaria at different scales. The fish spawn model is a macrolevel simulation, simulating how fish spawn in a natural environment. The purpose of the model is to help students learn about the relationships among different aspects of an aquarium ecosystem, such as the amount of food, initial gender ratio, filtration, water quality, reproduction, and fish population. The nitrogen cycle simulation presents a microlevel simulation of how chemicals reach a balance to maintain a healthy aquarium. This simulation allows students to examine the bacterial-chemical interactions that are critical for maintaining a healthy aquarium. In both NetLogo simulations, students can adjust the values of variables such as fish, plants, and food and observe the results of the adjustment, by sliders. Figures 1 and 2 show example screens from the two models. Counters and graphs provide alternative representations for students to examine the results of their inquiry. Students can observe the simulations, generate hypotheses, test them by running the simulation and modify their ideas based on observed results.

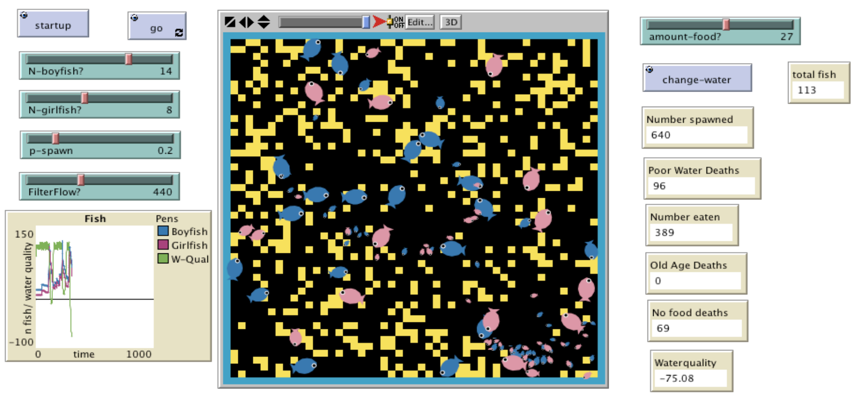

Figure 1. Screenshot of the Fish Spawn Model.

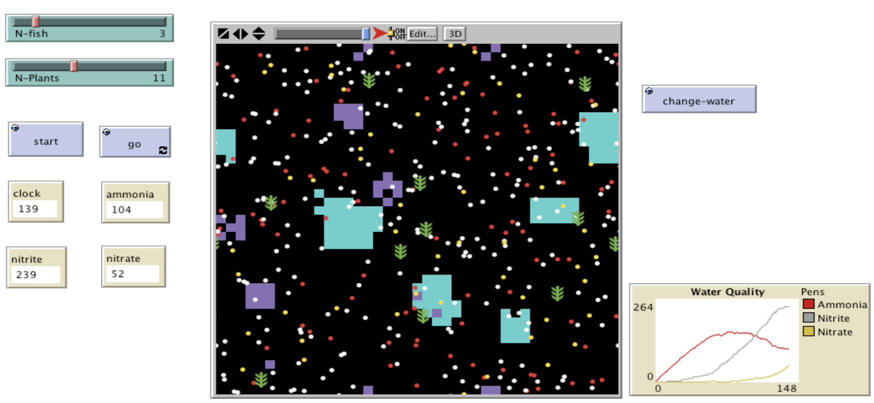

Figure 2. Screenshot of the Nitrogen Cycle Model.

Methods

The participants in this study were 145 middle school students from two public schools who volunteered to participate in this study. 70 were seventh graders taught by teacher A. 75 were eighth graders taught by teacher B. The study was conducted in seventh and eighth grades as part of students' science instruction.

The goal of our study was to support middle school science curriculum instruction and to promote deep scientific understanding of the aquarium ecosystem through the use of the RepTools. Towards this end, we designed a RepTools toolkit, as introduced in the previous section. The experimenters and the teachers worked together to develop RepTools curriculum units. Prior to data collection, the teachers participated in professional development on the content and tools.

In both classroom settings, the teachers used the RepTools toolkit to help students learn about the aquarium system. Before the classroom study, both classrooms had a physical aquarium model installed and maintained for about two months. The RepTools toolkit was installed on laptops for students to use while working in small groups. All learning activities were completed in small groups, which varied from 2 to 6 students.

The two teachers used different teaching approaches. One teacher (Teacher A) used worksheets with open-ended questions for groups while they explored the RepTools, and expected homogeneous progress for the whole class thus provided more directions than Teacher B. Teacher B was more inquiry-oriented. He tended to scaffold groups' progress with explanatory questions and prompted students to explain their observations. In addition, teacher B tended to allow heterogeneous progress among the groups and facilitated student learning by using open-ended questioning. Both teachers used the unit for approximately two weeks. As well, both teachers succeeded in getting students engaged in most of the learning events. In both classrooms, the teachers made connections to the physical as part of the curriculum unit. The students explored the hypermedia software in groups followed by other activities such as class discussions and construction of concept maps that connected parts of the system to their function. Then students were introduced to the NetLogo environment then collaboratively explored the two NetLogo models. They were encouraged to make connections across the two simulations and with the physical aquarium. Students took an individual pre and post test.

To examine learning outcomes, we coded the pre and post tests using an SBF coding scheme (Hmelo et al., 2000). Any presence of the structural knowledge, such as fish, plants, filter, was coded as structure. The presence of the mechanisms of the components was coded as behavior. For instance, the behavior of the plants is to absorb the carbon dioxide in the fish tank and produce oxygen through photosynthesis. The presence of the role of a component in the system was coded as function. For example, the function of the filter is to clean and circulate water. All protocols were coded blind to condition by one rater. To check reliability, another independent rater coded 20% of the data and the overall agreement was greater than 90%.

Results

A mixed 2x3x2 ANOVA was conducted with teacher (A and B) as the between-subject factor and time (pre and post) and SBF level (S, B, and F) as within subject factors. Table 1 shows the means and standard deviations of the SBF scores of two classroom settings for pre and post tests. There were teacher x time x SBF interactions in the aspects of structures and functions but not for behaviors (for structure, $F(1,143)$ =.6.06, p= .015; for function, $F(1,143)$= 5.27, p=.023). Specifically, students in teacher A's classes achieved more in structural and functional knowledge than students from teacher B's classes did. For both teachers' classrooms, there were significant learning gains in structures, behaviors, and functions (for teacher A, $F(1,69)$=38.01, p<.001, $F(1,69)$=24.48, p<.001, $F(1,69)$=285.56, p<.001, respectively; for teacher B, $F(1,74)$=15.20, p<.001, $F(1,74)$=71.23, p<.001, $F(1,74)$=62.64, p<.001, respectively). This suggests that after using the RepTools students understood more about structures, behaviors, and functions in their posttests than in their pretests. The effect sizes for both teachers' classroom settings are either moderate or large in terms of SBF (for teacher A, d=.78, d=.77, d=1.97, respectively; for teacher B, d=.54, d=1.23, d=1.19, respectively).

Table 1. Means and standard deviations of pre- and posttest SBF scores.

Teacher	Measures	Structure	Behavior	Function
A	Pretest	8.53 (1.68)	4.11 (1.82)	4.50 (2.24)
	Posttest	9.66 (1.17)	5.69 (2.22)	9.13 (2.46)
B	Pretest	9.32 (1.10)	4.91 (1.54)	7.10 (2.58)
	Posttest	9.88 (0.97)	7.11 (2.00)	10.53 (3.14)

Discussion

In the current study, we examined student learning using the RepTools curriculum and computer tools, a series of representational tools to support middle school science learning. These preliminary data analyses indicate the promising effects of the RepTools in supporting deep learning about complex systems and improving the teaching and learning of science. The conceptual representations embedded in the curriculum affected what students learned, as shown by the large gains particularly in the behavioral and functional aspects of the system. This is especially important because these are the aspects of the system that are most difficult to learn and are critical for understanding science. The visualization and manipulative opportunities provided by the NetLogo simulations afford students an opportunity to test and refine their hypotheses, which may lead to deeper understanding of complex systems. In addition, the results indicate that although the RepTools were used very differently by the two teachers, both achieved significant learning gains. The results of this study provided evidence about what students learned, but we need to better understand how the RepTools affected how students learned. In the future, we will delve deeper into the classroom and small group interactions and how these were mediated by the RepTools software through analyses of the video data and student artifacts collected in this study. Our future work will examine how to support students in modifying and constructing NetLogo models and how engaging in the modeling process can enhance students' understanding of scientific domains. The results of this study can inform future inquiry-based curriculum design in science education by indicating that the RepTools may be an effective cultural tool to provide meaningful experiences to help students collaboratively construct deep understanding about complex systems.

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