Learning with Ecosystem Models: A Tale of Two Classrooms

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Abstract: This paper explores how the RepTools toolkit was appropriated in two different classroom cultures. The RepTools toolkit consists of hypermedia about a complex system, physical models, and NetLogo simulations, designed to help students understand complex systems in the context of aquarium ecosystem. This paper reports on the nature of the different enactments of two teachers using the same tools. Although both classrooms showed similar learning gains, Interactions Analyses (IA) found differences between the enactments in two main areas; (1) providing opportunities for inquiry and language used to communicate and (2) teacher interpretation of the computer model. These findings suggest that how tools are appropriated is greatly influenced by teacher beliefs and classroom culture and that there may be multiple paths to productive use of such tools.

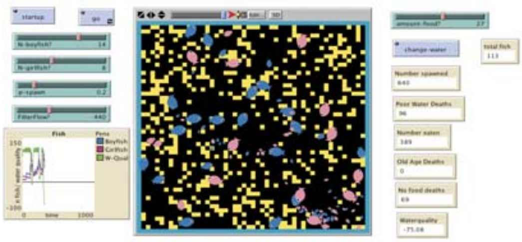
Introduction

Social constructivist and sociocultural perspectives on learning emphasize the role of tools and artifacts in mediating learning (Cole, 1999; Engeström, 1999; Palincsar, 1998). In such views, computer-based simulations and models provide affordances for engaging in scientific practices such as modeling complex phenomena (Clement, 2000). The norms for how these tools will be enacted as a part of classroom practice are affected by social influences such as teacher and technological scaffolding, student collaboration and discourse practices such as argumentation and explanation (Hmelo-Silver & Barrows, in press; Leinhardt & Steele, 2005). Even with an increasing emphasis on student-centered learning, the teacher plays important roles in setting the norms for classroom discourse (Webb et al. 2006). In a comparison of two enactments of a technology-supported curriculum, Puntambekar, Stylianou, & Goldstein (2007) found significant differences in the learning outcomes between the students of the two participating teachers using an innovative hypertext system as part of a simple machines curriculum. The more effective teacher helped connect activities within the unit and among concepts and principles while the less effective teacher spent more time giving instructions to the students and focusing on isolated task completion. These differences led to distinct classroom cultures and ultimately to differences in what students learned. Such studies provide natural quasi-experimental settings in which to examine how different approaches to computer-supported inquiry may affect student learning. In a similar vein, we examine the use of computer models in the domain of aquarium ecosystems. In particular, we report on how two teachers created different inquiry opportunities for students and appropriated the computer tools in different ways to foster student learning about complex systems.

Understanding the idea of complex systems is difficult, however necessary in modern society to be considered scientifically literate (Sabelli, 2006). Such systems are composed of multiple interacting levels with heterogeneous components and aggregate behavior that goes beyond the sum of the parts (Hmelo-Silver & Azevedo, 2006). Examples of complex systems range from ecosystems to gasoline combustion engines. With emergent processes, the behaviors of the constituent structures affect the aggregate behavior of the system through localized interactions (Jacobson & Wilensky, 2006; Wilensky & Reisman, 2006). Many of these interactions are invisible and dynamic, making them difficult to understand (Feltovich, Coulson, & Spiro, 2001). A deep understanding of complex systems requires perceiving the relations among components in the system, particularly among different levels such as structure and function. To learn about complex systems, students need experiences that engage them with complex systems phenomena (Jacobson & Wilensky, 2006). In particular, we argue that technological tools are critical for learning about these systems because they can make the invisible visible, allow interactions to be slowed down, sped up and replayed, as well as allow learners to manipulate different aspects of the system and gain dynamic feedback that supports building a deep understanding. However, simply providing the tools is not sufficient—they must be appropriated in productive ways as we discuss in the context of the RepTools project.

The RepTools Toolkit

The RepTools toolkit includes a function-oriented hypermedia (see Liu et al, 2007 for more details) and two NetLogo computer models (Wilensky & Reisman, 2006). The hypermedia introduces the aquarium system with a focus on function and provides linkages between structural, behavioral and functional levels of aquariums. By exploring this hypermedia, students can construct a basic understanding of the system to prepare them for inquiry activities with the simulations and as a reference to help students interpret the simulations. The two simulations present models of aquaria at different scales. The fish spawn model is a macro level 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, filtration, water quality, reproduction, and fish population. The nitrification simulation presents a micro level 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 simulations, students can adjust the values of variables and observe the results of the adjustment. 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.



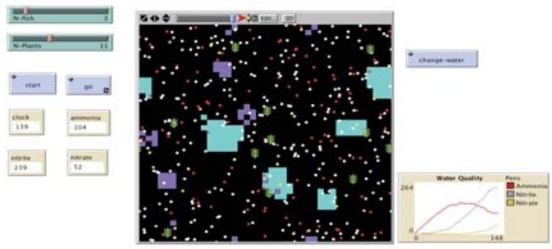


Figure 1. Screenshot of the Fish Spawn Model   Figure 2. Screenshot of the Nitrogen Cycle Model.

To develop the curriculum used with these tools, the research team met with the participating teachers for a one-week summer professional development workshop and as needed during the school year to develop instructional plans. This was a collaborative project with the goal of developing an instructional sequence that would fit each teacher's context and therefore be malleable under teacher established conditions in a classroom. Elsewhere, we have demonstrated that both teachers' classrooms had similar outcomes (Liu et al., 2007).

Methods

The participants were 145 middle school students from two public schools who volunteered to take part in this study. 70 were seventh graders taught by Teacher A and 75 were eighth graders taught by Teacher B. The study was conducted as part of students' science instruction. In both classroom settings, the teachers used the RepTools toolkit to help students learn about the aquarium system. Two months prior to the study, both classrooms had a physical aquarium placed in the classroom. Students used the RepTools on laptops while working in small groups, which varied from 2 to 6 students. Each teacher taught five classes. In each class, two focus groups were video and audio taped during the whole curriculum unit. Students completed individual pre and post tests (see Liu et al., 2007 for results).

These video data were analyzed using Interaction Analysis (IA), which involves collaborative viewing of video clips of a group of researchers to examine the details of social interaction (Jordan & Henderson, 1995). The basic goal of IA methodology is to use the video data to understand what people are doing during their social interactions and if, how, and what people are learning. We selected representative clips of critical events from both classrooms. These video clips include typical teacher-student interactions and student-student interactions during the critical events of analyzing the phenomena of the NetLogo models. We conducted ten IA sessions successively in our research group meetings to collaboratively review the selected video clips, describe observations and generate hypothesis. The goal of the IA was to gain insight on teacher-student interactions and develop a better understanding of how information was accomplished in the two classrooms.

The teaching styles for both teachers were distinct from the onset. The first teacher (Teacher A) created a teacher-centered classroom culture while the second teacher (Teacher B) adopted an inquiry-based approach to instruction. Both teachers shared the overarching goal of fostering students' understanding of an aquatic ecosystem, however, the strategies employed to reach this goal with the use of the RepTools differed. Teacher A used worksheets with open-ended questions for groups while they explored the RepTools, and expected homogeneous progress for the whole class and therefore provided more directions than Teacher B. Teacher B was more inquiry-oriented and 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. In both classrooms, the teachers made connections to the physical aquarium as part of the curriculum unit. The students explored the hypermedia in groups followed by other activities such as class discussions and construction of concept maps of the system. Students were introduced to the NetLogo environment and then collaboratively explored the two NetLogo models. They were encouraged to make connections across the two simulations and with the physical aquarium found in their classroom.

Results

The IA demonstrated differences in 2 major aspects between the two teachers; (1) how they created different kinds of learning and inquiry opportunities for students and; (2) how each teacher interpreted the use and purpose of the computer tools in their instruction. Although these aspects inevitably run together in creating classroom culture, it is of particular research interest to consider how such distinct styles and differences in approach can ultimately result in the similar learning gains found in Liu et al. (2007). Although both classes were classified as equally successful in terms of learning outcomes from a cognitive perspective, from a sociocultural perspective, Teacher B was more successful in enculturating his student to the scientific practices that one would engage in to understand complex systems (Crawford 1991).

It was clear that the two teachers held different beliefs about the nature of learning science, which led to differences in their classroom enactments. Specifically, Teacher A viewed learning as knowing about scientific content knowledge and judged student learning by evaluating content knowledge and task completion. In contrast, Teacher B viewed learning science as an epistemic process of reasoning and understanding and promote student learning by asking for elaboration and explanation of observed phenomena. As to assessment of student learning, Teacher A focused on prescribed artifacts (e.g., worksheets) while teacher B emphasized on the quality of student discourse (e.g., elaboration and explanation).

Creating Opportunities for Inquiry

The first major distinction between the two classroom settings is in the strategies the teachers used to provide opportunities for inquiry practices as well as in language used to communicate information. Teacher A used typical IRE model which focused students on listening and responding to the teacher (Cazden, 1986). Further, she tended to use everyday language in the class as a way to connect scientific content with students' prior knowledge. In contrast, Teacher B applied quite different strategies in his class. He paid tremendous attention to promoting students' reasoning and fostering important inquiry practices as he guided students, in essence, to engage in self-directed tool exploration. Further, he used scientific language in his discourse as way to incorporate new vocabulary into student learning. From the outset, the teachers conducted the units very differently. Teacher A engaged in whole-class discussions mixed in with content explanations whereas Teacher B began each class with guiding questions, introducing the unit by discussing the particular fish in the classroom aquarium and their endemic environment. As well, they differed in the opportunities they provided for student inquiry and the nature of the language they used to foster conceptual understanding.

Teacher A: Adoption of Student Language and Promotion of Short Answers

Teacher A's interaction with students was characterized by short-answer questioning and adoption of students language. Although Teacher A initiated classroom discussion by incorporating ideas that the students already knew, she concentrated on definitions for terms (e.g., non-living things) and posed questions to the class as a whole that required usually one-word (e.g., "yes" or "no") responses as shown in this next example:

> Teacher A: First of all you understand that certain things are living and certain things aren't. Right? Is ammonia a living creature?
> Class: No!
> Teacher A: It doesn't grow, it doesn't reproduce, it doesn't respond. How do I get more ammonia in the tank?
> Class: Pee
> Teacher A: Pee. It's not like its reproducing and making more. You want more. You want more, you get more fish and more fish do what?
> Class: Pee!

The questions asked were largely oriented towards reproducing declarative knowledge. The students seemed to have an understanding of what the teacher expected from their responses and obliged the teacher by answering "yes" or "no" to the teacher's inquiries, intent on responding correctly. By initiating such a short-answer questioning interaction with students, Teacher A did not provide opportunities for students to engage in scientific reasoning.

Another example of this type of interaction occurred when Teacher A tried to help the students understand ideas about scale as she explained how the NetLogo nitrification model simulates aquarium ecosystem on a micro level scale. The following excerpt exemplifies how Teacher A directed the students in a formal manner, where there was little room for deviation, or redirection, as the questions required short answers. She used more content-focused approach to instruction with few opportunities for students to engage in inquiry;

rather Teacher A asked largely rhetorical questions while she outlined what she considered to be the important facts as this next example demonstrates:

Teacher A: Does the ammonia just keep adding up in the tank?
Class: No
Teacher A: If kept adding up, what would happen to the fish?
Class: They die.
Teacher A. They die. So you remember when you did the nitrogen cycle we had all these red dots first, then the squares came up?
Class: Yeah
Teacher A: What did the square represent?
Class: Bacteria
Teacher A: What does bacteria do?
Class: It eats it.
Teacher A: So is bacteria living?
Class: Yes
Teacher A: How do you know?
Class: Cause it eats it.
Teacher A: Right. All living things, do they eat?
Class: Yes
Teacher A: Does every living thing eat?
Class: Yes
Teacher A: Does every living thing poo?
Class: Yes…
Teacher A: Do they reproduce when they are getting fed and are happy?
Class: Yes…
Teacher A: So the more ammonia you have, the more ammonia bacteria you make. Now, what does the ammonia poo? O a, sorry I mean bacteria. What does it poo?
Class: Nitrites
Teacher A: Right. It eats ammonia. This is the ammonia….

Teacher A also adopted student language and incorporated it into her explanation as a way to connect to student understanding. When the students answered her question about the source of ammonia as "fish pee", she incorporated it into her description of the nitrogen cycle. In an attempt to use their language and adopt their register, Teacher A went on to explain that bacteria "eat" the ammonia and "poos" nitrates that is eaten by other bacteria. It is important to note that Teacher A adopted student language as a way to convey the behavior of structures in a complex system as opposed to adhering to the scientific language used in the RepTools software. Teacher A's interactions suggests that she attempted to scaffold student understanding by connecting to their prior knowledge as a way to explain new scientific concepts.

Teacher B: Use of Scientific Terminology and Process-Inquisitions

Teacher B initiated class discussion differently. He typically asked open-ended questions. In one example, Teacher B asked the students "what is needed in the system?" This type of question served as a way to ignite conversation. This type of question left the future direction of the conversation in the hands of the students, based on their responses. One student answered "space." Teacher B responded by saying "Why? That's a one-word answer. I need…" at which point the student elaborated, "because…it helps with the lifestyle of the fish." Teacher B did not reject this answer, but asked the class to qualify the statement and pushed the students to delve further into the reasons as to why space is important in an ecosystem. Requiring students to justify their responses engages them in the scientific practices of explanation and argumentation provides an invitation for the students to continue their elaboration (Duschl, Schweingruber, & Shouse, 2007).

Teacher B also incorporated new scientific terminology into student understanding. By using terms like "ammonia" and "excrete" students adopted new terms into their vocabulary in their attempts to explain their understanding and in their hypotheses. In many of examples we studied, we found students adopting a scientific register by qualifying their statements with language introduced by the teacher. Where Teacher A adopted student language in her explanation, in Teacher B's class we found the students adopting the teacher's scientific language, both in student-teacher interactions, and in student-student group interactions. Teacher B's students used terms modeled after teacher explanation to explain behaviors such as "excrete," "ammonia" and "produce."

Alexis: What would happen [if there were no fish]?
Courtney: Well first of all, uh, snails wouldn't have anything to eat.

Ron: We're not talking about snails.
Alexis: We're talking about fish.
Courtney: But they need to have… they wouldn't make the water dirty. So then the fish wouldn't have…
Ron: Alright, so they wouldn't produce waste. We're not talking about the snails.
Alexis: I just think that there would be no point. What are we going to have a plant farm in water?
Courtney; Basically, nothing would be able to work because the bacteria…
Jenn: Everything lives on fish.
Courtney: The fish produce ammonia, which bacteria makes less harmful and snails keep the water clean by cleaning the waste and the algae.
Ron: OK, so fish are the basis of all this… ecosystem.

The use of appropriate language became a norm for this group of students as they elaborate their ideas, construct explanations, and challenge each other with questions. They appropriated the language of the domain and appeared to use it comfortably.

Interpretation of Computer Models

Second, the IA demonstrated that the different teaching styles and classroom cultures had a clear effect on the use and interpretation of the computer simulations. We found that Teacher A used the NetLogo simulation as a device to motivate student learning, while Teacher B used it as a cognitive tool to develop reasoning skills and scientific epistemic practices.

Teacher A: Technology Use to Provide Instruction

Teacher A interpreted the NetLogo computer models as a teaching aid meant for instruction. Teacher A explained to the students that the NetLogo simulation was a model of real-world phenomena that is not normally seen. Rather than formally encouraging hypothesizing about observations taking place during the modeling simulation, she seemed concerned with ensuring that the students understood the concept of a model as a tool. She tended to use the micro level simulation as an illustration to help students visualize the microscopic processes. The following example highlights her appropriation of the tool in this manner as she began to explain the nitrification process to the entire class and discussed a representation key (a handout she provided for the class that helped the students recognize what the individual model structures represent).

Teacher A: Let's go over the key. Did you figure out what this is?
Class: Yeah.
Teacher A: What is it?
Class: Plants.
Teacher A: Brilliant, that's a plant, you got that one. [Writes it on board] Did you get the red dots What's that?
Class: Ammonia.
Teacher A: Very good. OK now I'm going to make it a little harder. White dots?
Class: Nitrite.
Teacher A: Because what appeared first?
Class: Ammonia.
Teacher A: Red dots. And what appeared second?
Class: White dots.
Teacher A: And then you started seeing…
Class: Nitrate. [pause] Nitrite.
Teacher A: [changes "Nitrate" to "Nitrite" on the board] See this is where our fish tank went different. This is supposed to come second. Remember our fish --- we did it the other way, it was kind of weird. So then after the white dots appeared you saw yellow dots so they would be the….
Class: [mixed response of "Nitrite" and "Nitrate"]

As this example demonstrates, Teacher A used the simulation to reinforce the content that she had already explained to the students, rather than as a tool for student inquiry. It seemed important that the students correctly explain the nitrification process in terms of the objects in the simulations and not, as in the case of Teacher B, as a way to foster student inquiry and scientific exploration.

Teacher B: Technology Use as a Cognitive Tool

Teacher B used the model as a cognitive tool to stimulate student cognitive engagement. In contrast to Teacher A, Teacher B used the RepTools toolkit with a clear cognitive goal. He required the students to apply certain cognitive skills, such as the development and testing of hypotheses and the collection of empirical data to support and monitor ideas. Unlike Teacher A, he explained how to use the RepTools to foster deeper understanding by promoting student interaction with the tool that mirrored parts of the scientific method. The following excerpt shows how Teacher B scaffolded students to develop and support specific hypotheses based on the data they collected. In this way, Teacher B regarded the RepTools as more than an illustrative device meant for instruction (like Teacher A) and instead allowed the students to understand through manipulation, interaction, and interpretation.

Teacher B: Now how are we going to know…
Jenn: For the nitrite should I put grey or white?
Teacher B: Well on here, it looks kind of white to me. Now, how are you going to know whether the blue boxes are snails, bacteria, what's the other stuff you said, algae, stuff like that?
Courtney: I don't think it's bacteria because the red is ammonia and it's not eating, it's not getting rid of it.
Teacher B: How do you know that?
Courtney: Because, um well, you can see the ammonia on top of it and it's not doing anything to it.
Teacher B: Well it's paused right now.
Courtney: Well also because the ammonia is increasing and while these things are increasing too it's not decreasing the amount of ammonia.
Teacher B: It's not?
Courtney: No, well that's what I observed. Am I wrong?
Teacher B: No, no.
Ron: Say that again, Courtney…
Courtney: I said, I think that the blue can't be bacteria because bacteria eats ammonia and while the blue is increasing the ammonia is still increasing too so if the blue was bacteria…
Jenn: What about the purple?
Courtney: I'm not talking about the purple.
Jenn: Do you think the purple could be bacteria?
Ron: I'm going to start it again and we'll see if it starts eating any bacteria.
Jenn: No, it starts building up more but now look at the purple.
[students are speaking at the same time]
Jenn: The purple might be bacteria

Again, as with Teacher A, small group tool-use mimicked the way in which Teacher B presented the tool to the students. Our analysis showed that students gathered information, hypothesized, and tested then independently iterated through these steps as a way to construct an understanding of the system. Teacher B's students used the tool as a way to develop a deeper understanding through inquiry and observation. In the next example, a group of students in Teacher B's class attempted to make sense of the simulation and elucidate the representations of the figures on the screen. One student noticed that "nitrate thrives in unclean water" which elicited the comment "so is nitrate good or bad?" The students went on to develop an experiment to test this question by allowing the water quality to go down so that they could observe what happened, and then develop hypotheses as to why.

Hal: Okay, I think the red dots are ammonia [laughing].
Mindy: Now why would you get that idea?
Hal: I don't know.
Keith: Nitrate thrives in unclean water.
Hal: So nitrate is bad or good? Isn't nitrate good?
Anna: And then whatever's after ammonia, that's bacteria.
Mindy: It's an earthquake, ahh. Okay, now they're like equal.
Anna: Okay. So let's do this…
Hal: Well why is it unclean water?
Keith: Max out everything. Stop changing the water.
Anna: Everything's gonna start rushing inside.
Mindy: Okay, maybe bacteria dissolves nitrates.
Anna: See, the bacteria came.
Mindy: Because before we didn't have that much bacteria…
Anna: And now there's a lot of bacteria too…

Mindy: …which means that they're eating all the ammonia and the nitrate…nitrite
Anna:…And then nitrite came.

Here the students went beyond interpretation of the literal meaning of the representations. They also tried to understand the significance of the nitrification process in the aquarium. The students were co-constructing knowledge as they questioned each other and built on each other's ideas working in a community of inquiry.

Discussion

Our most notable finding was that the two teachers created very different enactments that used the RepTools in very different ways and that these differences mediated very different classroom conversations. Specifically, the teacher who took a content-oriented approach (Teacher A) tended to encourage classroom discussion that linked content knowledge to prior knowledge and used the technology to motivate students. In comparison, the teacher who took an epistemic approach (Teacher B) tended to encourage classroom discussion that emphasized scientific terminology and reasoning. He used the technology to introduce scientific language and to foster reasoning.

These differing approaches had consequences for the nature of the classroom discourse. While both teachers encouraged a mix of large and small group discussions, the first teacher adopted a short-answer approach that reinforced the concepts but limited the extent to which students could engage in the epistemic practices of science. The second teacher was able to promote reasoning and engagement in inquiry practices. While promoting epistemological thinking is an important goal for a middle school science classroom (e.g., Reiser, Smith, Tabak, Steinmiller, Sandoval & Leone 2000), teachers may have a hard time balancing inquiry-related demands with the need to promote content knowledge (see discussion in Holbrook & Kolodner 2000).

In classrooms, creating opportunities for students to think critically about complex phenomena means that students need opportunities to ask questions, generate and test ideas, and collect data and evaluate evidence (Jeong & Songer, in press). Teacher scaffolding is critical for helping learners both engage in inquiry practices and developing deep understanding of science content (Duschl et al., in press; Krajcik, Blumefield, Marx, Bass, Fredricks, & Soloway 1998). While computer-based tools can provide extraordinary opportunities for engaging inquiry in these ways (Lajoie, Lavigne, Guerrera, & Munsie, 2001; Lee & Songer, 2003), our results support the notion that orchestrating tool-mediated learning about complex systems is a difficult task and how different teachers appropriate and interpret these tools in their classrooms can lead to very different enactments (Puntambekar, Stylianou, & Goldstein, 2007). Despite these differences, comparable and impressive content gains occurred in both classrooms but our observations suggest that opportunities to engage in inquiry practices were, however, different in the two classrooms.

What is clear from this study and others (e.g., Puntambekar et al., 2007) is that providing computer-based tools is not a guarantee that they will be used in a particular way. It is important for researchers in the learning sciences to understand what the tradeoffs are in different kinds of enactments. Some enactments are reasonable adaptations whereas others might be what Ann Brown (1992) considered lethal mutations. In this research we advanced our understanding of how different modes of using the same computer-based tools supported different kinds of learning opportunities and have the potential to lead to the development of different kinds of learning outcomes.

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