Understanding the *Why* and Uncovering the *How*; Transfer of Conceptual Representations

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Abstract

Some of the common critiques against the classical approach of transfer have put the spotlight on questions related to the conditions that facilitate transfer, the context of instruction, and the pertinent cues that learners need to be able to identify that signal the application of appropriate problem solving strategies. This study looks at transfer from two alternate perspectives in a study of middle school science students. Instruction is organized around Structure-Behavior-Function (SBF) as a conceptual representation to support learning about different complex systems within a technology-rich environment. Our results suggest that technological affordances and use of SBF as a conceptual framework, prepares students to be "better prepared for transfer".

Keywords: actor-oriented transfer, preparation for future learning, impact of technological affordances, understanding complex systems

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Transfer is an important goal of schooling as educators hope that what students learn in school will be useful beyond the initial instructional context. Important questions for educational researchers are how instructional tools and contexts can facilitate or impede transfer. We argue that one tool for transfer is conceptual representations (Liu & Hmelo-Silver, 2009; Sinha et al., 2010). Our interest is in the role of conceptual representations for understanding complex systems. We focus on complex systems because they are an important element of science literacy (Sabelli, 2006). We propose that the Structure-Behavior-Function (SBF) conceptual representation can help learners organize their knowledge of complex systems (Goel et al, 1996; Hmelo Silver et al., 2007).

We have developed instruction and technology-based tools that use SBF representations to teach middle school students about complex aquatic ecosystems (Hmelo Silver et al., 2007, 2009, 2011). We make SBF visible through hypermedia, simulations, and an SBF modeling tool (Hmelo-Silver et al., 2011). In this paper, we report on a study of transfer in this technology-rich environment from the perspective of contemporary theories of transfer. The goal of this research is to understand how students construct relationships and similarities between two systems: an aquarium used during instruction and a problem posed about a local pond as part of a post-instructional interview. We consider transfer from both actor-oriented (Lobato, 2006) and preparation for future learning perspectives (Bransford & Schwartz, 1999) to investigate how students transfer content knowledge between two aquatic ecosystems.

Theoretical Background

Contemporary theories of transfer argue that transfer is a dynamic process that involves active construction on the part of learners. An actor-oriented approach illuminates how learners construct similarities between situations, focuses on which connections are made, on what basis, and how and why those connections are productive from the learner's perspective (Lobato, 2006). The preparation for future learning (PFL) perspective focuses on the strategies adopted by students in knowledge rich environments and their ability "to learn a second program as a function of their previous experiences" (Bransford & Schwartz, 1999, p. 69). We believe that providing a knowledge rich learning environment that promotes the usage of SBF will prepare students for understanding different complex natural systems (Hmelo-Silver et al., 2007). The integration of these two perspectives on transfer is crucial to understanding the importance of activities and experiences (from an actor oriented perspective) that prepare learners to transfer content knowledge between two complex natural systems.

This study has two goals. The first is to identify the conceptual ideas that were transferred, if any. The second goal is to trace learning trajectories and look for evidence of SBF thinking as students make sense of a new complex system.

Tools to Promote SBF Thinking

The focus on PFL is to understand the learning strategies adopted by the learner in knowledge rich environments (Bransford & Schwartz, 1999). We worked on creating a knowledge-rich technology-intensive learning environment that would prepare the students to learn about this conceptual representation. The curriculum unit is organized around using a classroom aquarium as a model of an aquatic ecosystem. Affordances of the three technological tools supported this learning. First, the knowledge-rich hypermedia (see Figure 1) is organized around what, how, and why questions which correspond to structures, behaviors, and functions (Liu & Hmelo-Silver, 2009; Hmelo-Silver et al., 2007). Second, students work in groups to explore macro (see Figure 3) and micro (see Figure 4) levels of the aquatic ecosystems using NetLogo simulations (Wilensky & Reisman, 2006). From a PFL perspective the simulations serve dual purposes: they enable students to gain multiple perspectives and also provide a platform for collaborative sense making (Hmelo-Silver et al., 2009). The third tool that was used was the Aquarium Construction Kit (ACT; Goel et al., 1996, 2009). This was designed exclusively to promote thinking about the SBF as a representational framework. It allows students to jointly create models and label them in terms of SBF. The models can be constructed either in a table (see Figure 2b) or graph (see Figure 2a) format. The model table focused students' attention on thinking about various structures in an ecosystem. The first task is to identify whether the components are biotic or a-biotic. Secondly, the three column table affords the opportunity for students to think about structures, their multiple behaviors and functions. In addition the ACT software also had a section titled 'Notes' devoted to maintaining a virtual laboratory notebook. This enables students to record their notes and observations related to the modeling process, simulations and use of hypermedia. Use of the simulations and ACT are critical from a PFL perspective as they provide opportunities for students to generate questions which shapes their learning goals (Barrows, 1985; Bereiter & Scardamalia, 1989).

Methods

Participants

Data collection involved videotaping twenty-five middle school students over two weeks as they worked through the curriculum unit through a combination of small group and whole class activity and discussion. On the last day of instruction, twenty students were interviewed and given a task designed to assess knowledge transfer. The students were selected by the teacher as representing a heterogeneous sample in terms of academic performance in science. Three researchers asked each student to read a brief newspaper article about fish dying in local lake and then to suggest possible causes for fish mortality and to identify conditions essential to maintain a healthy pond ecosystem. Data sources included interviews, classroom observations and video recordings. Interviews and video data were transcribed.

Instructional Context

Our research site was a public middle school located in Northeast United States. This study is part of a larger research that investigates middle school students' understanding of aquatic ecosystems. The instruction was embedded in the science curriculum incorporating state science standards.

The curriculum unit began with students developing an understanding of the terms structure, behavior and functions. In whole class discussions, they developed an understanding that it is possible for a single structure to have multiple behaviors and functions. Next, using the ACT software they worked collaboratively on creating a naïve model of an aquatic ecosystem.

Their teacher then introduced students to the macro and micro level NetLogo simulations. In the macro simulation, they attempted to understand the relationship between the size of fish population and water quality. The micro simulation focused on the process of nitrification. In this biogeochemical process, the ammonia that fish excrete gets converted by one kind of bacteria to nitrites, that in turn are transformed by another type of bacteria to nitrates. The design of the simulations facilitated discussion around identifying various components, observing their behaviors and predicting their functions. Students could also access the function-centered hypermedia for a rich knowledge base of relevant biogeochemical processes and physical components relevant to an aquarium. Although the teacher did not push students towards using this resource actively, they were aware that they could access it if they needed additional information and clarification. Students navigated between the simulations and hypermedia. Students were also encouraged to make use of the 'Notes' section within the ACT software to maintain a running commentary of the information they learned, observations on the simulations, the hypermedia and the process of modeling the aquatic ecosystem.

Using the knowledge gleaned from the hypermedia and simulations, students then revised their naïve models. Their revisions included addition of new components, relations in terms of behaviors and functions and eliminating irrelevant structures, behaviors and functions that they no longer considered relevant. Finally, students shared their models with the rest of the class to get feedback on improvements and clarifications.

Data Analysis

Data analysis was a two-step process. First, while reviewing the interview transcripts the researchers attempted to sort, classify and identify relevant episodes

(LeCompte & Preissle, 1993) which demonstrated: (a) how students' used SBF as a representational construct; and (b) how students transferred concepts from the aquarium unit. The second step involved going over the video data of students working on the aquarium unit to identify emergent processes and learning trajectories that may have led to transfer. A top down approach identified instances that demonstrated SBF thinking, followed by inductive data analysis that articulated the processes that led to transfer.

The ideal assessment from a PFL perspective would explore people's abilities to learn new information and relate their learning to previous experiences (Brown, Bransford et al., 1983; Bruer, 1993; Singley & Anderson, 1989). Thus, we designed interview questions (see Appendix A) that would trace the students' learning trajectories and also investigate if students were prepared to make sense of a new aquatic ecosystem. Students were asked to articulate possible causes for sudden fish deaths in a lake. We wanted to observe whether student responses drew upon SBF as a representational construct to make sense of the biogeochemical processes that caused this problem scenario. From an actor-oriented perspective this was critical, as we wanted to understand the trajectories followed by the students, if they viewed the two ecosystems (lake and aquarium) as similar. In addition, we wanted to understand if prior experience with SBF (promoted by the technological affordances) prepared them to use it in a new ecosystem.

Results

Although all the students participated in the same knowledge rich environment, we observed differences in the nature of content knowledge that students transferred. For example, sixteen students identified at least one connection between the two ecosystems in terms of common structural components (for e.g. water temperature, algae growth).

Four student responses demonstrated connections between visible and invisible structures and their multiple behaviors and functions.

During the curriculum implementation, we observed differences in how students used the technology in their small groups. Although some groups used the hypermedia as a source of information to complete their model table; others drew from patterns and trends they observed in the simulations to guide their thinking. For the purpose of our study we used a case study approach (Merriam, 1988). We focused our attention on four students (Riya, Neel, Nina and Shane, all pseudonyms) whose post interview responses demonstrated SBF thinking. Our analysis examined the processes these students used to unpack a new problem using SBF thinking and trace the influence of affordances of technological tools that facilitated this transfer.

Patterns emerged from data analysis suggesting differences in the nature of content knowledge that students transferred. From an actor-oriented perspective (Lobato, 2004; 2006), scrutinizing classroom discourse and technology use helped in identifying the learning trajectories followed by the students to view similarities between the two systems. From a PFL approach (Bransford & Schwartz, 1999), the suite of technological tools promoted SBF thinking and prepared students to use it as a conceptual representation to understand new complex systems.

Using Information Learned from Knowledge-rich Environments

During the interview process, students were asked to position themselves as scientific experts to articulate conditions essential for maintaining a healthy lake ecosystem. In the excerpt below, Riya highlights the importance of maintaining the right temperature for fish survival:

1. First I would look at how the temperature changes.
2. And when fish are having the right amount of food and temperature.
3. And then compare it to what time of year they are dying.

In lines 1 and 2, Riya establishes a baseline by identifying amount of food and ideal temperature as important factors needed for fish to survive. Next, she decides to test her hypothesis by comparing it to the months when the fish are dying. It is possible that she is drawing from her experiences with the aquarium unit to think of possible solutions to solve this problem.

To understand how Riya viewed the two complex systems as similar and to identify down the source of her knowledge, we used a semi-structured interview that allowed us to follow up on her responses. Here the interviewer asked probing questions to understand what was being transferred and processes that led up to this the transfer:

1. *Researcher:* So what you're saying is that maintaining the temperature is an important part for maintaining a healthy aquatic ecosystem. How do you know that?
2. *Riya:* Well I learned it from that program we were doing earlier this week.
3. *Researcher:* Which program the simulations, the hypermedia, the-?
4. *Riya:* The hypermedia.
5. *Researcher:* Did you spend a lot of time on the hypermedia?
6. *Riya:* Yes we did.
7. *Researcher:* Why?

8. *Riya*: Because there was a lot of information there. And we had to find out what were the functions and factors needed for healthy aquatic ecosystems. And the hypermedia had a lot of those kinds of information.
9. *Researcher:* So the information you read in the hypermedia, did you use it anywhere?
10. *Riya:* Yes we used it in the model table.
11. *Researcher:* How long did you spend time with the hypermedia?
12. *Riya:* Any time we ran out of ideas we went back to it. I'm not sure how long it was.

In this excerpt Riya identified the hypermedia as an important source of information for her group, which is notable, as the teacher did not actively promote the use of hypermedia. She also stated that the information from the hypermedia was used to complete the model table and that she focused on the "functions and factors."

A closer analysis of Riya's response allows us to observe her learning trajectory from an actor oriented perspective and also reveals the processes that prepared her to m a make sense of the new problem. In line 8 she talks about functions and factors. The hypermedia and the ACT models promoted the idea that all structures behave in a certain way based on the functions they are expected to perform.

Lines 3-12 suggest the learning trajectory that Riya followed. She noted that she spent time gathering information from the hypermedia. This suggests that repeated information gathering from the hypermedia and studying that information under the SBF lens within ACT, helped her perceive a functional similarity between both ecosystems. In addition browsing through the hypermedia made her aware of the possibility of influence of multiple factors on sustaining healthy aquatic ecosystems. From a PFL perspective this is important as it prepared her to consider multiple factors that might be influential for sustaining any complex natural system. It may also have helped her to think of multiple connections between structures and consider more complex causal relationships.

Knowledge rich environments such as ACT prepared students to unpack new complex systems. For example, in the following interview excerpt, Neel identifies the impact of high temperature on the lake and also reflects on the conditions needed to support a healthy aquatic ecosystem:

1. *Neel:* I guess it could have affected some of the chemicals in the water. It could have set off a chemical reaction that could have polluted the water so that the fish couldn't live in it.
2. *Researcher:* So are there any chemical reactions that you might think about that may have been affected by the heat?
3. *Neel:* Umm…(*shakes his head no)*
4. *Researcher:* So what are the kinds of questions that you would ask to get more information?
5. *Neel:* I would ask for the population decrease. Like how much less fish were there. I would also ask for chemicals, like the levels of ammonia and other factors that would have been observed, but not to an extensive level.
6. *Researcher:* If you were a scientist what kind of conditions would you recommend as essential for maintaining a healthy aquatic ecosystem?
7. *Neel:* I would say filter the water out, whenever it becomes below a certain level, like we did in the project.

8. *Researcher:* How would you filter the water out in a lake?
9. *Neel:* Umm…you could make a filter or transfer the fish to another source of water that's not polluted. I think you should limit the amount of food so that there are no harmful chemicals in the form of waste. And also you shouldn't keep the food low as well or else the fish can die.
10. *Researcher:* How would having too much food be a factor for causing fish to die?
11. *Neel:* When there's a lot of food, the fish would keep eating. As a result they would release a lot of waste. And then the waste becomes ammonia. And not enough bacteria would be there to like make the ammonia non-toxic. If the fish eat too much, the ammonia could spread and they could all die.
12. *Researcher:* Umm you mentioned bacteria. So what does that do?
13. *Neel:* Bacteria makes it, converts the ammonia into non-toxic chemicals.

In line 1 Neel argued that changes in the chemical environment are important to understanding the problem. Although he was unable to clearly articulate the chemical processes, his responses reflect his understanding that maintaining good water quality is vital for fish survival. From a PFL perspective, analysis of this interview revealed two instances that highlight Neel's ability to learn from a knowledge-rich environment. The first instance was in line 7 when he thinks aloud about using a filtering process similar to what he and his group had used with the Netlogo simulations. The simulations had a filtration setting that could be used to dilute the water. He elaborated upon this in lines 9 and 11 by explaining that having too much food prompts the fish to eat and release more waste. Second, his comment about the increase of toxic chemicals (in line 11) such as ammonia being a cause for fish to die was a direct parallel to what the students observed within the Nitrification simulation. When imbalances between the fish population and the size of the aquarium became too large, the simulation displayed the pop up message, “Ammonia is too high, the fish will start dying. Better change water NOW.” We think that it was the awareness that excess of fish waste (ammonia) can lead to death of the fish that influenced the group (and indirectly Neel) to focus on factors that influence water quality and need for filtration.

Balance it out

It was our intention to encourage the students to think about the importance of maintaining balance between various components of aquatic ecosystems. We ensured that both simulations emphasized this idea. The macro-level simulation was designed to explore the concept of carrying capacity. While engaging with the simulation, the students were asked to think about this concept in several ways (such as “How can you keep the fish alive for a long time?”). After spending some time with this simulation, we observed that students competed with one another to keep the fish alive the longest! In the next example, we show how this concept helped us to understand student transfer from both an actor-oriented strand and PFL perspective.

In identifying prerequisites of a healthy lake ecosystem, Neel suggested that changes needed to be made to the pond ecosystem if it was not favorable for fish survival. In the following excerpt he explained what he would change:

1. *Neel:* Well, I’d find out how the ecosystem worked before and compare it to what happened afterwards. Then if it’s something unnatural and is

really messing up the ecosystem and try to fix that. Or if its something that keeps happening its really natural it keeps changing and you don't need to change it in order for it to be ok. Depending on what was wrong you would have to change it. If some part of the whole thing was imbalanced, you would have to balance it out to make sure everything stays the same.

2. *Researcher:* How would you maintain the balance?
3. *Neel:* By having equal number of things.
4. *Researcher:* The equal number of what?
5. *Neel:* Equal number of animals and plants that are actually there. If the ratio of plants and animals was low then add more plants so that the animals have more food and usable energy to fix it.

In line 1, Neel discusses the idea that it's important to consider balancing components within the ecosystem in case there's a problem. Next, in lines 3 and 5 he says that having an equal number of animals and plants is important in how he interpreted the idea of balance. During initial data analysis we speculated that Neel viewed the two ecosystems as similar as got this idea from the macro level simulation. From an actor-oriented transfer, we wanted to trace his learning trajectory. So we reviewed video footage of a classroom discussion that the students had with their teacher on the patterns they observed within the macro level simulations:

1. *Ryan:* 90% of the fish get eaten when they are spawned.
2. *Sheena:* Too many fish equals poor water quality.
3. *Teacher:* To keep the fish from dying what do you have to do?
4. *Neel:* Try to maintain a balance.

5. *Teacher:* A balance of what?
6. *Neel:* Water cleanliness and how much a fish eats?
7. *Teacher:* Filter flow.

From line 2 it's evident that the students are aware that an imbalance in fish population impacts water quality. In addition, Neel perceived the existence of several components in definite proportions with each other as important for sustaining fish life (in lines 4 and 6). We speculate, from a PFL perspective, that it is possible that he drew upon this classroom discourse when asked to think of possible solutions to the transfer problem. In addition, from an actor-oriented approach this helps us identify a particular incident that may have led him to view the two ecosystems as similar.

Speaking in SBF

We realized that classroom instructions, social interactions and focusing on what students attend to (Lobato, Ellis & Munoz, 2003) play an important role in strengthening transfer within knowledge-rich environments. Organizing instruction around SBF as a representational tool served to make the underlying relationships within systems salient. As part of the aquarium unit, the technological tools emphasized these connections (by function-oriented questions in the Hypermedia, organizing ideas around SBF in ACT and observing micro and macro level processes using simulations). Students had multiple opportunities to think about SBF as a representational tool. This prepared them to think about new complex systems using the SBF framework.

In the excerpt below the Riya says lack of food is a possible cause for fish death. When probed, her explanation demonstrates SBF thinking. After the researchers asked "Why was there a decrease in food?", Riya responded:

1. They said that there was extreme weather condition. So like some fish eat plants.
2. So the amount of *(pause)* maybe there was a difference in the amount that plants grew and *(pause)* maybe photosynthesize could have affected the food.

Riya's response reflected SBF thinking as she identified the behavior of fish (structure) was to eat plants; the function of plants is to photosynthesize and act as fish food. From a PFL perspective, this response suggests that prior exposure to SBF prepared her to understand the cyclic nature and interconnectivity of various components within an ecosystem. Recall that Riya identified the influence of various factors as important for maintaining a healthy aquatic ecosystem. In this example, she acknowledged that multiple factors affect available food and, subsequently affect fish mortality.

We wanted to trace Riya's learning trajectory and identify the possible experiences with the technology and classroom interactions that may have led to transfer. The following excerpt is taken from the first day that these two students begin working on the model table. Riya suggests they write down seaweed as one of the structures. Neel writes it down under the structure column.

1. *Neel:* Ok…that's biotic. Component behavior?
2. *Riya:* Umm…food source…no?
3. *Neel:* So what? So what does the seaweed do?
4. *Riya:* Um…
5. *Neel:* It photosynthesizes. Ok…why?
6. *Riya:* Um….

7. *Neel:* To create glucose and live.
8. *Riya:* To live and be a food source for other animals.
9. *Neel:* No…I know. But that's not its purpose. The seaweed isn't there so that its food for other people.
10. *Riya:* Ok…um…yes it is there for that.
11. *Neel:* No its not! It's there for itself.
12. *Riya:* And for that!
13. *Neel:* Its not born like that. Like if it was living you don't say, "Hey, junior seaweed you're going to grow up and your purpose is to get eaten. So make sure that you're nice and tall and plump so that some animal can eat you."
14. *Riya:* Ok then what's the purpose?
15. *Neel:* Cos they want to live right? Not want to they have to live. They photosynthesize *(pointing to the behavior column)* in order for cellular respiration *(points to the function column).*

He then wrote down the function and behavior of seaweed and then wrote the next structure, i.e. the sun.

16. *Neel:* Ok sun. Component behavior?
17. *Riya:* Gives light or energy.
18. *Neel:* It gives off energy. Does it really have a reason to give off energy? Why does it give off energy?
19. *Riya:* Yes it gives off energy so that living things can grow.
20. *Neel:* But that's not the purpose of it!

21. *Riya:* You can't say that! There are many purposes for each structure.
22. *Neel:* And we have to find one of the purposes.
23. *Riya:* Yes and one of the purposes is to.
24. *Neel:* Well the sun is not there to give off energy.
25. *Riya:* Well the sun may have direct purposes that may also be indirect. Like the sun may not feel that its need is to give off energy to the plants but it does.
26. *Neel:* But that's not the reason. It's a by-product that it does give off energy to the plants.

This excerpt showcases the difficulty of being able to succinctly articulate the behaviors and functions of components. The model table initiates the students to question the actions (what) or behaviors of structures (as asked by Neel in line 3). Next, it prompts students to think about the purpose (functions) or 'why' a certain component behaves in a certain manner. In lines 5, 14 and 18 Riya and Neel are pushing each other to clearly articulate the reasoning behind the functions. In addition, in line 21 Riya displays the understanding that it is possible for a single component to have multiple functions. From a PFL perspective it's useful to know that students can use SBF as a representational tool with a different complex system.

Evaluating quality of learning experiences

Our findings reflect that students benefit from their experiences in knowledge-rich environments. Students were able to view the two ecosystems as similar and as a result make use of their knowledge in new problems. In the next two examples, our focus is on their ability to use their knowledge of the aquarium ecosystem to think about possible causes for fish mortality within the lake ecosystem. In the following interview excerpt, Nina discusses the possibility of three factors that are responsible for fish deaths:

1. *Researcher:* So you said intense heat may be a factor. Besides the heat is there anything else that you think may have caused the fish to die?
2. *Nina:* Maybe like excessive plant growth. Like algae. If algae gets light from the sunlight it grows. And excessive algae growth is harmful for the fish. So that may have caused the fish to die. So there's a relation between algae growth and fish.
3. *Researcher:* So what you're saying is that there are two possible causes for fish death, intense heat and excessive algae.
4. *Nina:* Also algae also take in a lot of oxygen, so that may have deprived the fish from oxygen.

In lines 2 and 4, Nina discussed the behavioral (algae grows in sunlight) and functional (algae deprive oxygen from the fish, if they grow excessively) role of algae. To trace Nina's learning trajectory, we reviewed the classroom videos of Nina and her teammate Shane. The excerpt below is taken from a day when they created models using the model graph feature in ACT:

1. *Nina (writes on the relation between sun and algae):* The sun provides light energy for the algae to turn into food through the process of photosynthesis.
2. *Shane:* Click on the red line, right click it. What does it say? Convert the relation into a function. Oh yes we can do that. Cos see here that's a relation *(points to the relation between algae and sun)*

3. *Nina:* So some of these relations on this page are functions, right? Like algae produce oxygen, that's a function of algae right, it's not just a relation.

This discussion between Shane and Nina serves dual purposes for the sake of our analysis. First, it gives us a sense of their growth in conceptual understanding of SBF. In line 1, Nina identifies the existence of a relation between two structural components—algae and sunlight. This is followed by the realization that this relationship can also serve to highlight the functional purpose of one or more components. And finally in line 3, Nina acknowledges that producing oxygen is a functional operation of algae (structure). This suggests that students' understanding of the underlying connections between various components, their behaviors and functions is increasing as a result of engaging in this learning environment. Secondly, it highlights the affordance provided by the model graph that facilitates this understanding. As students had to think about the link in the model graph, it focused them on thinking about the relationships between the structures. This is important from a PFL perspective as it allows us to trace the experiences that led Nina and Shane to go beyond surface level relations between structural components and think about underlying behavior and function connections. In her interview, we have additional evidence of how various technological affordances prepared Nina to interpret a new aquatic ecosystem:

1. *Researcher:* Earlier you identified three different causes for fish dying intense heat wave, algae bloom and that the algae would take in excessive dissolved oxygen in the water. So how do you know all these things?
2. *Nina:* Oh…through the system. Earlier we didn't know anything. But then we saw the simulations and then we saw the homepage.

3. *Researcher:* The homepage, you mean the hypermedia?
4. *Nina:* Yes, that's what I mean the hypermedia. You can make connections. Like if ammonia is what the fish excrete for waste and then that gets converted to nitrite, then that gets converted to nitrate. Then there's all these different connections that you can make. And the graph helped to make these connections clear.

In line 1 the researcher directs Nina's attention to identify the source of her knowledge. For the purpose of clarification, she asks if the hypermedia is one of the possible sources. Nina's response (in line 4) indicates that she and her teammate drew upon the micro level simulation on the process of nitrification (see Figure 4) and also upon the hypermedia to gather information. In addition, this response also discusses the affordance of the ACT software in helping students realize that there are underlying behaviors and function connections between multiple structures.

Evaluating the quality of learning environment is important from a transfer perspective. It helps us trace Nina's learning trajectory from an actor-oriented perspective. From a PFL strand it helps us identify the affordances of the technologies that facilitate learning in knowledge-rich environments. In the next finding we focus on the technological affordance of asking questions that promote SBF thinking.

Generating questions

An important application of the PFL perspective while evaluating the learning environment is focusing on the questions that are generated by the students. Bransford and Schwartz (1999) discuss that one determinant of the course of future learning is the questions students ask about a topic, because these questions shape their learning goals.

The function-centered hypermedia (see Figure 1) draws the students' attention to think about different structures in terms of their behaviors and functions. The model table (within ACT) prompts students to think about various components within an aquarium under the SBF framework. The table (see Figure 2b) headings are in the format of 'Component (What)', 'Component Function (Why)' and 'Component Behavior (How)'. During the interview we asked students to generate questions they felt were critical to understanding the cause of fish death. These questions included:

1. "What is good water quality?"
2. "What is the exact temperature of the water?
3. "What kinds of organisms are in the water? What do they eat? What is their waste?"
4. "How much ammonia and nitrite are in the water?"

The question in line 1 asks about the functional importance of water quality. Students appear to be focusing on structural elements in line 2. The questions in line 3 are important as they display a direct understanding that the structural component (organisms in the water) have two behaviors (eating and releasing waste). Questions in line 4 serve dual purpose. First, it implies that students are aware that water has certain invisible structures (ammonia and nitrite) and secondly, that it's important to know their proportions in water. It is apparent that students have started to question the problem in terms of SBF representations. From a PFL perspective, we speculate that prior experience with using a specific type of representational framework has provided students with the tools they need to unpack another complex system. Eberbach and Crowley (2009) discuss that asking 'what' questions are akin to those generated by expert biologists during data collection who regard them as a "productive strategy for extracting information from observed phenomena." 'How' questions highlights the need to investigate current conditions and immediate causation.

The findings of this study present a promising picture in terms of understanding students' transfer of knowledge about complex natural ecosystems. Our choice to focus on the actor-oriented strand in conjunction with PFL adds to the body of literature on alternative practices of studying transfer.

Discussion

Our study contributes to research on contemporary approaches to transfer (Lobato, 2004, 2006; Bransford & Schwartz, 1999) by looking at new ways for understanding learning trajectories. This study is clearly limited based on these few case studies. Nonetheless, they provide a glimpse into how students see relationships across different systems and how a conceptual representation can be a powerful tool to prepare students for future learning. SBF as a tool can help students unpack complex systems. Experience with this tool prompts students to consider the possibility that there are visible and invisible connections between different components within a complex system. Each structure behaves in a specific manner as a result of the function it is expected to perform. In addition, it presents the possibility that a structure exhibits multiple behaviors as it is governed by numerous functions. We believe that knowledge and application of SBF as a representational tool can prepare students to understand biogeochemical processes that are a part of the national science standards.

Our goal here is to identify features within the learning environment that make it salient for the students. Lobato, Ellis & Munoz (2003) discuss the relevance of instructional environments, social setting and influence of what students pay attention to within the learning environment. From a design perspective these factors are critical to help create instructional units that facilitate and encourage transfer of knowledge.

As we observed the students' responses to the interview our focus was not assessing mastery over content knowledge. A close analysis of student interview data suggest that students are thinking in terms of SBF albeit not necessarily mirroring expert thinking, suggesting that the students are constructing their own ways of seeing similarities. The results illuminate the affordances of the technologies used within our study that supported the transfer we observed. We provide the students with a knowledge-rich environment as Bransford and Schwartz (1999) suggest is important for PFL. The results show that the hypermedia provided students with a fund of knowledge that they could use to answer a problem in a different context. The modeling toolkit scaffolded students in think about complex systems in terms of their multiple connections that are visible and invisible. The simulations provide opportunities for students to compare perspectives, negotiate meaning thereby preparing them for future learning.

Further research in this field will be critical for preparing students to be proficient for the 21st century. The focus has now shifted from students' ability to replicate what they have learned in the classroom to being able to apply that knowledge in real life situations. This research is a step in that direction. Our goal is to design rich knowledge-based learning environments that ensure students attend to key aspects that will prepare them to become scientifically literate citizens.

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Appendix A

Step 1

Ask the student to read the following story that was published in the newspaper:

Hundreds of fish perish in North Brunswick lake

BY CHRIS GAETANO Staff Writer

Something fishy floated to the top of North Brunswick's Hidden Lake on Sunday. Late that afternoon, residents reported the stench of rotting fish emanating from the lake area, which prompted a quick response from the township. The smell, it was revealed, was a layer of fish that died and floated to the top of the water in numbers estimated by the township to be in the "several hundred" range.

The fish, according to Janice Larkin, assistant to Mayor Francis "Mac" Womack, were a combination of catfish and sunfish.

According to New Jersey's Department of Environmental Protection spokeswoman Darlene Yuhasz, this type of situation tends to happen during heat waves. "It's not particularly unusual given the extreme weather conditions we had last week. It's not uncommon to see fish kills this time of the summer, and when you factor in the extreme weather conditions we experienced last week, it's not surprising," said Yuhasz. Hidden Lake is an approximately 4-acre, man-made water body located in the township's Hidden Lake residential section.

Step 2

1. Why do you think the fish died?

Prompts:

- *What do you think may have caused the fish to die?*
- *Why do you think those factors may lead to the death of the fish?*
- *How do you think this particular cause that you just mentioned caused the fish to die? (If they talk about a list of possible factors, then ask them to illustrate the impact of each factor on the death of the fish).*

If no microscopic components are mentioned, then ask:

Are there any things that we can't see that might have contributed to the problem at Hidden Lake?

2. Are there any other possible causes/explanations for the fish deaths? If so, what are they?

Prompts: Explain why you think those causes might have caused the fish to die. Anything else?

3. If you were a scientist, what conditions would you recommend as essential to maintaining a healthy aquatic system in Hidden Lake?

Prompt: What kind of question would you ask to get more information about the problem?

4. Should people worry about the fish dying in a small man made lake in North Brunswick?

Prompts: If yes, why and if no, why not?

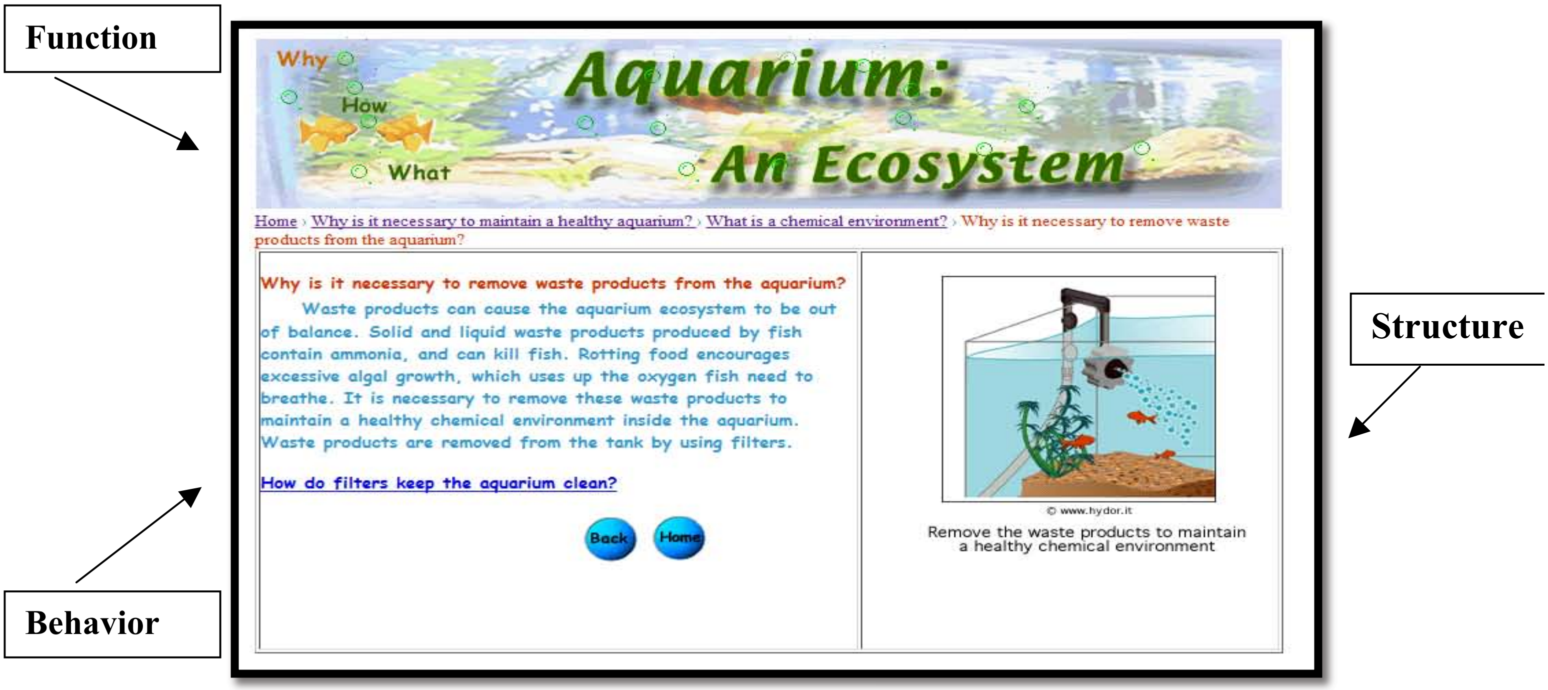
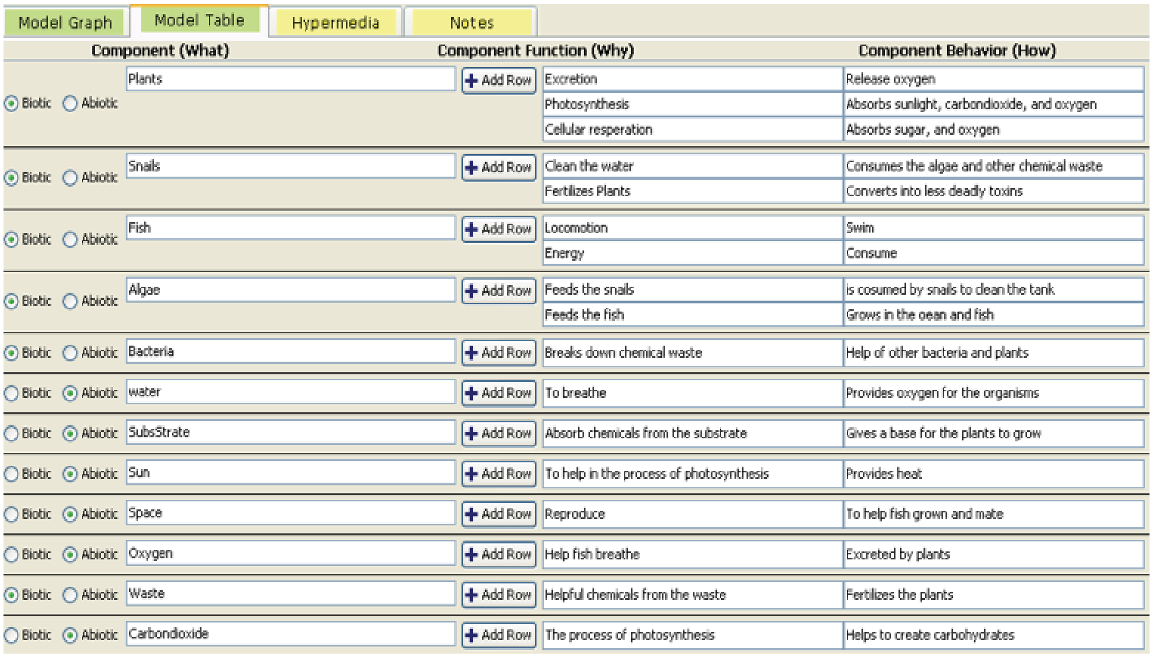


Figure 1. Function centered Hypermedia

Figure 2a. Aquarium Construction Toolkit (Concept Map view)



Model Graph | Model Table | Hypermedia | Notes

Biotic/Abiotic	Component (What)	Component Function (Why)	Component Behavior (How)
Biotic	Plants	Excretion	Release oxygen
		Photosynthesis	Absorbs sunlight, carbondioxide, and oxygen
		Cellular resperation	Absorbs sugar, and oxygen
Biotic	Snails	Clean the water	Consumes the algae and other chemical waste
		Fertilizes Plants	Converts into less deadly toxins
Biotic	Fish	Locomotion	Swim
		Energy	Consume
Biotic	Algae	Feeds the snails	is cosumed by snails to clean the tank
		Feeds the fish	Grows in the oean and fish
Biotic	Bacteria	Breaks down chemical waste	Help of other bacteria and plants
Abiotic	water	To breathe	Provides oxygen for the organisms
Abiotic	SubsStrate	Absorb chemicals from the substrate	Gives a base for the plants to grow
Abiotic	Sun	To help in the process of photosynthesis	Provides heat
Abiotic	Space	Reproduce	To help fish grown and mate
Abiotic	Oxygen	Help fish breathe	Excreted by plants
Biotic	Waste	Helpful chemicals from the waste	Fertilizes the plants
Abiotic	Carbondioxide	The process of photosynthesis	Helps to create carbohydrates

Figure 2b. Aquarium Construction Toolkit (Model Table view)

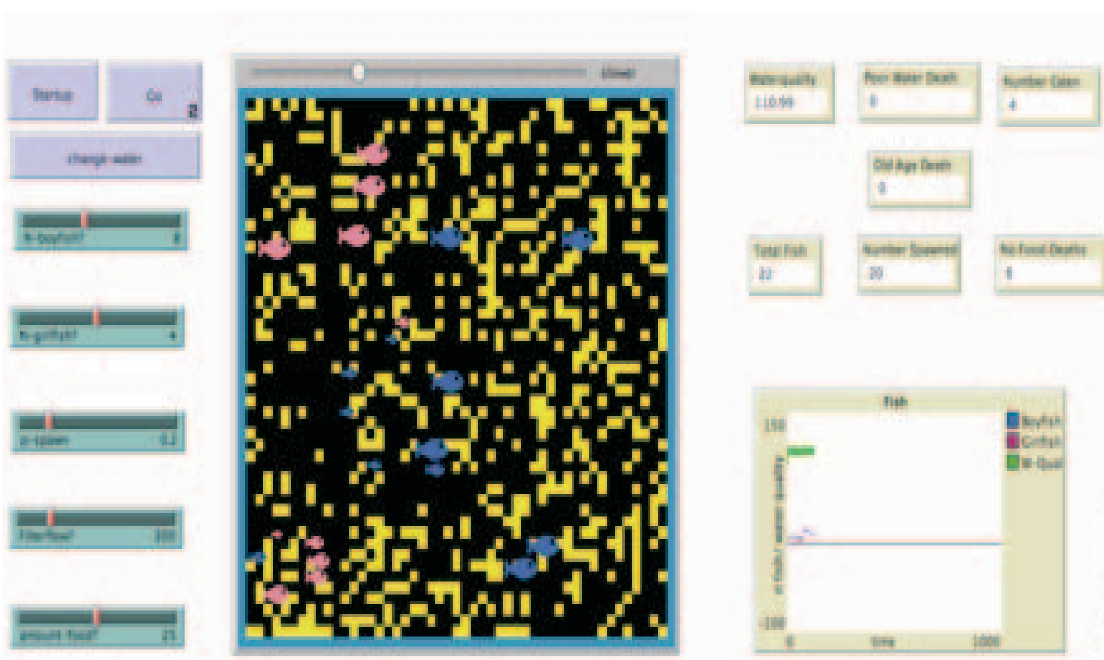


Figure 3. Macro-level NetLogo Simulation

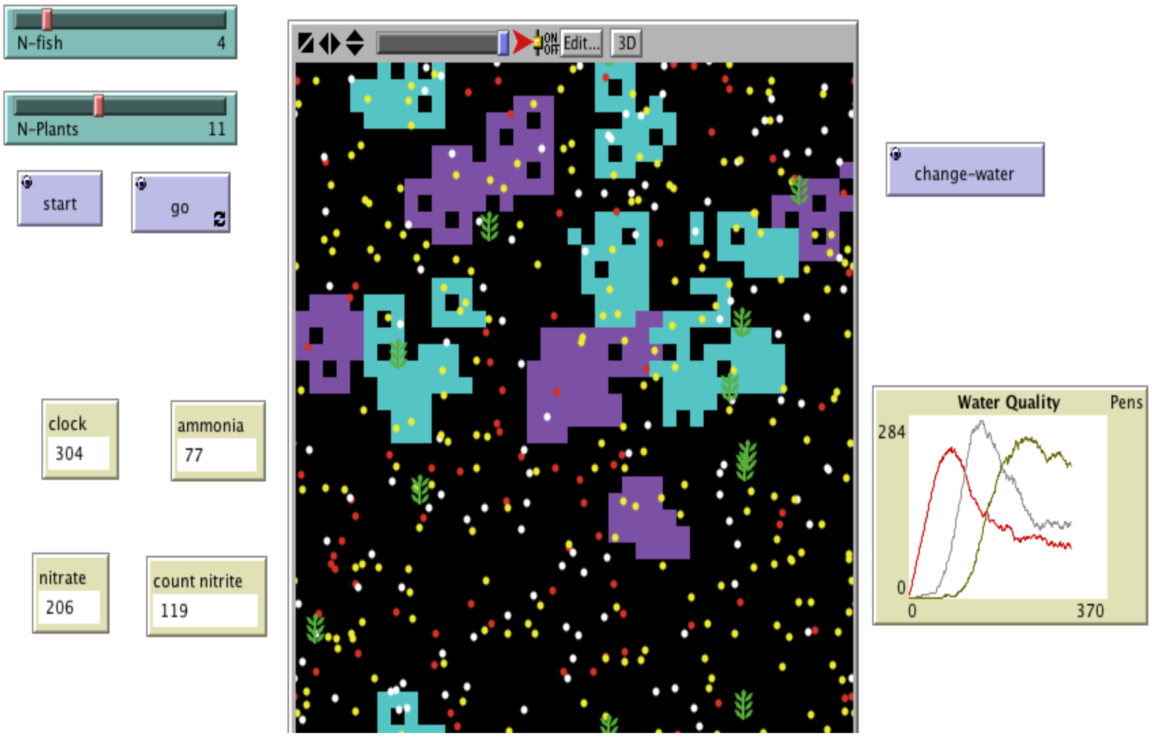


Figure 4. Micro-level NetLogo Simulation