

Appropriating Conceptual Representations: A Case of Transfer in a Middle School Science Teacher

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Abstract: This paper presents a case study in which a middle school science teacher modifies her classroom instruction and teaching materials using the Structure, Behavior, and Function (SBF) representational framework to transfer her reasoning about one natural system (an aquarium ecosystem) to another natural system (human cells and body systems).

Promoting an understanding of complex systems is a difficult yet important component of scientific literacy (Sabelli, 2006). Through emergent processes and localized interactions, the behaviors of a system's components affect its overall function (Jacobson & Wilensky, 2006). These interactions are often dynamic and invisible which make them difficult for learners to understand and presents challenges for teachers (Feltovich et al., 2001; Hmelo-Silver et al., 2007).

The Structure-Behavior-Function (SBF) conceptual representation allows students to understand the relationships between the structures, behaviors, and functions of systems and to map SBF across multiple levels. In the science classroom, academic researchers have developed tools utilizing the SBF representation as a way to teach about multiple complex systems (Hmelo-Silver et al., 2007; Liu & Hmelo-Silver, 2009). Structures are defined as the components of a system, behaviors as the mechanisms or processes that occur within a system and functions as system outputs (Goel et al., 1996; 2009). We present a case study of a teacher who appropriated the SBF conceptual representation that was originally introduced by a team of researchers, to create tools to meet her curricular needs. The focus of the study is to understand how the teacher transferred the use of the SBF representation between two different curriculum units. 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 (Lave, 1988, Bransford et al., 2000; Mestre, 2003). The study looks at transfer under two alternate perspectives and the possible synergy between using multiple perspectives to study transfer.

Our study considers transfer from both an actor oriented approach (Lobato, 2002, 2006) and a preparation for future learning perspective (Bransford & Schwartz, 1999) to investigate the teacher as learner applying knowledge in a new area. We look at the influence of previous activities and procedures adopted by a learner to construe similarities in new situations (Lobato, 2006). In particular our interest is in understanding how a teacher constructs the relationships and similarities between two systems; one provided by researchers and one designated by the teacher. Adopting an actor oriented perspective requires considering which connections the learners make, on what basis, and how and why those connections are productive (Lobato, 2002). Evidence for transfer from this perspective is found by scrutinizing a given activity for any indication of influence from previous activities. Additionally, we investigate how a greater understanding of SBF might have contributed to transfer from a preparation for future learning (PFL) perspective. This provides a framework for evaluating the quality of particular kinds of learning experiences (Bransford & Schwartz, 1999). The PFL perspective allows us to uncover strategies that have been adopted to interpret a new situation; "Interpretation of the situation invariably involves some use of a previous experience it cannot be reduced to a simple replication of that experience" (Broudy, 1977, p. 11). Integration of these two perspectives on transfer was crucial to understanding the importance of activities and experiences (from an actor oriented perspective) which prepare the learner to develop new concepts that, in this case, focuses on transfer between complex systems.

A Case of Transfer: The Instructional Context

The context for this study is a technology-intensive curriculum unit that helps middle school science students learn about an aquarium ecosystem using SBF as a conceptual representation. The learning environment is comprised of two parts; (1) Reptools toolkit and (2) The Aquarium Construction Toolkit (ACT). The RepTools toolkit includes a function-oriented hypermedia (Liu et al, 2007) and NetLogo computer simulations (Wilensky & Reisman, 2006). The hypermedia (Figure 1) introduces the aquarium system with a focus on function and provides linkages between structural, behavioral and functional levels of aquariums. In addition, two NetLogo simulations are included to make the macro and micro level behaviors visible to the learners. The second component to the learning environment, ACT, allows students an opportunity to organize their understanding about complex systems by explicitly identifying structures, behaviors, and functions in both an SBF table (Figure 3) and through concept mapping which allows relationships to become explicit (Figure 4). This gives the students an opportunity to understand both individual mechanisms and the meta-level concepts related to complex systems (Goel et al, 2009)

In this study, we highlight a particular case in which a teacher participant, Ms. Y, who has been working with the SBF Aquarium curriculum for more than five years, developed her own instructional tools using the SBF representation and computer-tools to meet her classroom teaching needs. In the fourth year of enacting the SBF Aquarium curriculum, Ms Y used the SBF representation as an instructional tool to teach about the cell and human body systems (digestive, reproductive, respiratory etc.). The result, in collaboration with another science teacher from the same school, Ms. T, was the creation of a human body system hypermedia modeled after the function-centered aquatic hypermedia.

Methods

To characterize how the SBF representation is appropriated by Ms. Y and to understand the processes by which the teacher transfers these tools to other domains, we adopt a qualitative approach. An interview with the teacher and video analysis sessions were conducted to understand (1) why the teacher transferred her understanding of SBF to new instructional domains and (2) how she transferred these understandings. We held an interview session with Ms Y after she had completed teaching about both the systems. The primary focus of the interview was to understand how she conceived the idea of extending the computer-based representational tools beyond what was expected from her, the influence of her prior knowledge during this process and her attempts to prepare herself to solve new challenges. After the interview transcription, we looked for evidence of mechanisms for transfer and how the teacher constructed similarities between aquarium and body systems.

To understand the nature of transfer in Ms. Y's teaching of the content, we selected representative clips of critical events from Ms. Y's classroom that demonstrates evidence for using the SBF as a tool to teach about another complex system. These video clips included whole class discussions that Ms. Y has with her students while (1) introducing the SBF concept for the aquatic ecosystem the year before she created the cell/body unit (2) introducing the SBF concept for the aquatic ecosystem the year she employed her cell/body unit and (3) explanation of SBF and modeling of the cell/body unit. These clips include three classroom interactions for all three time interactions under evaluation. 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 the means by which people interact in social environments and how, if any, learning takes place. We conducted nine IA sessions successively to collaboratively review the selected video clips, describe observations, and generate hypotheses.

Results

Teacher Created Hypermedia

Ms Y., in collaboration with her colleague Ms. T, created a hypermedia in the form of an interactive PowerPoint of the cell and body systems mirroring the aquarium hypermedia developed by the research team (Figures 1 and 2). The teacher hypermedia outlines the different structures in the system along with leading 'why' and 'how' questions. The 'how' questions are directed towards understanding the behavioral aspect of system components and the 'why' questions focus on functions. The teacher created hypermedia was developed as additional learning resources to textbooks to connect cell systems to higher order body systems. Neither the body system hypermedia nor the use of modeling these systems using the ACT software was planned by the research team; the teachers did this of their own volition.

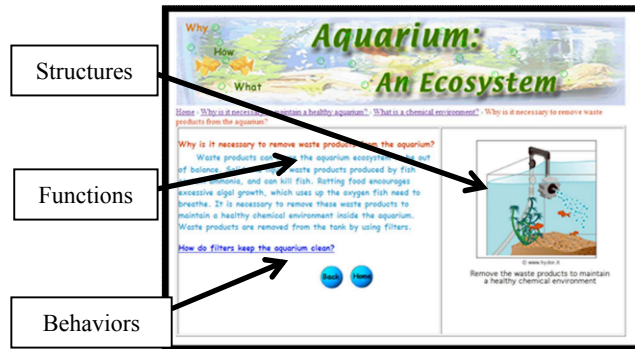


Figure 1. Researcher-developed hypermedia

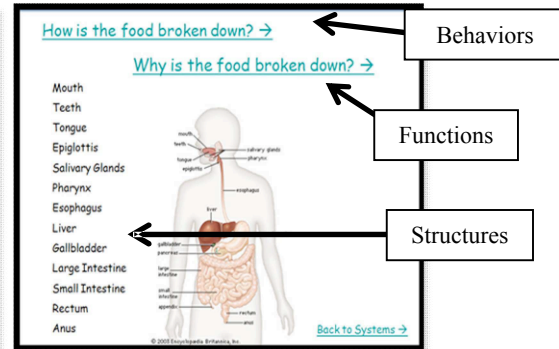


Figure 2. Teacher-developed Hypermedia

Identifying similarities through the SBF lens

Ms Y's initiative to extend and appropriate our research and develop additional classroom tools led us to consider the process of transfer. We intended to understand the processes she adopted to draw similarities between what she had been teaching for several years (the aquatic ecosystem) to the current unit she developed (cell and body systems). Adopting an actor oriented perspective helped us to articulate which connections she makes, on what basis, and how and why those connections are productive (Lobato, 2002). A PFL approach allowed us to understand how her learning experiences may have prepared her to apply the SBF representation when she created her new hypermedia. Our hypothesis, based on the interview, is that she used the SBF as a tool to trace similarities across complex systems. For example, consider the response when both Ms Y and Ms T were asked about the utility of their hypermedia:

Researcher:...what is the purpose of the Hypermedia you guys came up with? And how does it help you teach about complex systems?

Ms. Y.: Okay, first we were teaching the cell. And we also have to teach body systems especially in the new standards, so its going to work out that we're actually covering both of those. But they teach the cell as an isolated entity. And we were saying that you know the whole body is made of cells and you know you teach the systems separate, you teach the cell separate, and then we just name the parts of the cell and tell what each part does. And there's no connection about how the parts interact, interact with each other in the cell, let alone how the cell interacts with the whole body.

Ms. T: Because kids don't even know that each- Like you're bodies is made up of cells, they just think of it as cells.

Researcher: Everything discrete?

Ms. T: Right. ..., everything's separate and that you know, the idea that everything is made up of different types of cells and the cells work together; they just don't get that, at all.

Ms. Y: Right, and it's a hard concept to get. So, what we were thinking about is like the kids actually think when they eat food it breaks down and then leaves the body. They don't get that the food has to go to the cells and the cell actually works and creates energy from this food and then there's a waste and it sends that back to the body for it to be excreted. So we're trying to give them not only the names of the parts and what each part does individually but how it needs to work-

Ms. T: I would say we're trying to bring in the behavior into it. They get the structure, we teach part the function, but there was never that behavior why does it need to do what it does....

Ms. Y: And we're doing the behavior not only of the cell itself but behavior of all the systems and then the behavior of the whole body. And the cells are all part of that whole body.

This excerpt highlights that Ms. Y understood that the cells are an integral part of the body systems and cannot be taught in isolation. She discusses that systems in the body are not disconnected and have complex mechanisms which allows for higher order operation. It is apparent that she understands how structures within a system perform multiple behaviors in order for it to function effectively. Owing to the strong connection to the SBF representation, we felt it critical to observe the learning trajectory she adopts to refine her understanding of the SBF as a conceptual tool. This led us to analyze Ms. Y introducing the SBF concept (via IA sessions) over multiple years to determine how she may have refined her own

understanding of SBF as a basis to then extend it into a new area.

Refining SBF as a Conceptual Tool

Upon examining Ms. Y's classroom introduction of SBF over time, analysis of the video suggested that her understanding of the SBF representation as a conceptual tool changed. She adopted several distinct strategies to introduce the topic of complex systems ranging from discrete (the year before she developed her unit), to acknowledging complexity (the year she developed her unit), and finally providing a systems perspective with her new cell/body unit. The year before developing her new unit, she began her introduction to the SBF representation by mentioning the new terminology being used to discuss the system, however, she introduced structures, behaviors, and functions as individual constructs that should be dealt with discretely. In the following year, she promoted the SBF representation as a comprehensive perspective, acknowledging it as a conceptual unit. Finally while introducing it within the context of the unit on cells and body she explains it as a system, complete with nested subsystems and stressed the importance of inter-relatedness.

Ms. Y's early introduction to SBF suggests a focus on linear connections. This is shown by the way in which she fills out the ACT SBF table (Figure 4) in front of the classroom. As a way to connect ideas about the Structure, Behaviors, and Functions, she drew clear conceptual lines between one structure at a time and all the behaviors exhibited by that structure as the following example shows:

Ms. Y: We just named them all yesterday ... The heater, the fish, the plants. Those things are called the structure. The next word we're gonna use is Behavior. The behavior is what the fish do. What do the things do in the tank? And the next word we're gonna use is Function, okay? So what I want to do today ... to start with structure and behavior..... So, I made a chart and ... The first column is the structure, or the parts. So everyone write down one of the things in the fish tank is fish. and the second column I wrote was behavior, and the third column I wrote was function. We're going to start with this second column which is behavior. When I ask you the behavior of something, I want to know is what does it do?

Ms. Y: "What do fish do?" Swims, eats, breathes, and poops. Okay, all fish swim. That is their behavior okay. They swim. What else do fish do?

Andy: Breathe

Ms. Y: They breathe. What else do fish do?

Andy: Eat..

This excerpt indicates that, after covering structures the day prior, she begins by describing the meaning of the term 'behavior'. This was immediately followed by establishing all linear connections between the structures (fish) and the multiple behaviors (swims, eats, breathes, poops) that this structure exhibits. After promoting an understanding of the behavior exhibited by the structure (fish), she then drew another relationship between each individual behavior to the last column to indicate the behavior's function.

Over time, Ms Y's introduction to the SBF concept became richer and more complex. In the excerpt below taken from the year after she developed her unit, she describes SBF as interconnected entities within a system, rather than discrete elements on a worksheet:

Ms. Y: Okay, now, let's do the filter..... I'm gonna do the filter with you and then you're gonna do one on your own. Alright, so... what does the filter do? What does the filter do? Jim what does the filter do?

Jim: Um, cleans out the tank

Ms. Y: Cleans the tank. Or cleans the "what part of the tank?"

Jim: The water in the tank?

Ms. Y: All right, so the filter will clean the water. Okay? Now, why does it clean the water?

Jim: So it can put more oxygen into the water?

Ms. Y: No. That's another thing that it does. It actually, because it's spinning around, because it's spinning like this, it's actually, one of the things it does- we could make a second bullet- is it adds oxygen to the water. Now, this part here, why does it do it? First of all, I want to stop right here. The filter is this big grey thing here. Right? Now, first of all, how does it work? What's this big tube doing? *[Points to picture of filter on the screen.]*

Pat: Sucking up the water

Ms. Y: Sucking up the water. Then the water comes up here, right? And it gets sucked up and it goes back here and it pours back down. When it flushes back over that's when the oxygen

from the air can get pulled back into the water. Okay, so how- you said it cleans the water- how does it do this?

Pat: Well, it has in the filter. The filter has like chemicals and stuff... well like, (inaudible) right here, we're gonna start with the fish tank. This bag, because right here..

Ms. Y: What do you think is in this bag?

Pat: Bad stuff

Ms. Y: Well, eventually the bad stuff is going to get in here, but actually there's charcoal in here, gravel in here. And then when the water flows through it, can it catch all the big chunks?...Maybe the fish feces and stuff like that? So, and then see how it spins back down here? Water splashes and it's pulling in the oxygen. So now... Alright, so now, why does it clean the water? What is the point of cleaning the water? Because of the what? Right, it keeps clean water for the who?

The class went on to discuss the fish and the plants, and how the filter aerates the tank and what the filter does for the whole system. In this example, when Ms. Y discussed the behaviors (cleans water in tank) and function of the filter (by collecting feces from fish) she was guiding students' answers to S, B, and F simultaneously and filling in the chart appropriately rather than focusing on any one aspect in isolation. Ms. Y also used student answers to generate more questions that linked what (Structure) and why (Function) questions throughout her classroom discussion, highlighting the complexity of how the system works.

Later in the same year, when introducing her unit on the cells, Ms Y emphasized how the SBF within a system work as a whole across multiple levels, not directly, but implicitly by leading questions as seen from the example below:

Ms. Y: Eventually what we want [the researchers] to do for us is allow us to model systems within systems. What happens if I can click on the cell and zoom in on that and put the cell parts in there? Because they don't have the ability to zoom right in on that one part, are there any ideas on how to connect the cell through modeling to the other body systems? Because you also want to go and look at the function. What do you think?

Lucia: Umm, what about if you like umm put a picture of the cell.

Ms Y: Yeah but I want to drive everything to the cell because that's, you know, the whole body operates to get things to the cell, you know that right? But then I also want to show what the cell does inside once you send the food there. So how can I show that part? How can I show it on this graph? Okay. You know how this is a system. The body parts and the cell is its own little mini system, how can I show the stuff inside the cell? Should I circle all the mitochondria right around the cell? Or should I pull the cell out and make that part separate? ...Okay so here on this side we'll do all the body parts connected to the cell, and over on this corner do you want to do the cell again and show the inside of the cell..

These excerpts demonstrate the process of refining of Ms. Y's thinking about the SBF concept as a conceptual tool. Whereas earlier, her focus was primarily in working with living organisms in the aquarium (fish), she later introduced a new level of complexity by trying to relate the influence of non-living structures on other living organisms. She was still focusing largely on structures but she does make connections to behaviors and functions. In addition, she helped students understand that one structure may have multiple behaviors and functions. Comparing her SBF introduction of the cell system here to that of the aquatic ecosystem in the earlier unit, she presented it to the class as an entire system and not as fragmented pieces as S, B & F with linear connections. In addition, when applying SBF to the cell, Ms. Y introduced a meta-perspective by explicitly explaining that the task was to represent their ideas through modeling. Moving away from the isolated task provided in earlier in the context (i.e., filling out the table by first listing structure followed by behavior, and then function) Ms Y explained that the students are going to organize their knowledge in the table graph. By placing emphasis on the modeling tool and providing students with the starting point of the structure, the cell, Ms Y explains that the task is to develop a representation of their ideas about the human body system, using the table to organize their ideas and providing the students with leading questions that she had provided earlier when talking about the SBF in the aquarium unit.

This process of transition led us to believe that Ms Y. was an active learner herself. As she explored the aquarium hypermedia and talked about SBF representations in her class, she frequently asked questions to the research team and her colleague Ms. T., to refine her understanding. We think this experience had two effects. First, it helped her identify and address the gaps in her understanding, which prepared her for future learning. Secondly, it shed light on the processes that she as an actor (learner) use to

construct similarities between the aquatic ecosystem and cell system (Lobato, 2002).

Recognition of Teacher as a Learner

In the interview, Ms. Y indicated that since the beginning of her involvement in the project, her knowledge has continually developed. She explained that she was the primary source by which information was passed from the research team to the students and that, over time, she felt that she has become more competent in this role. Effective learners learn to look critically at their current knowledge and beliefs (Bransford, Brown, & Cocking, 2000) instead of making old responses by simply associating new information to the existing concepts or schemas. In the following excerpts from the interview, she acknowledges her lack of mastery over the content and is aware that she refined her ideas of the SBF representation and the aquarium unit which lead to adoption of the new unit:

Okay, my knowledge of this still develops every year because it's knowledge that [Project PI] had and it- you know- was her angle on something and then I had to try to understand what was going on in her head. So it's taken me many years of practice and talking to [Project PI], talking to [researchers in the room], to kind of get this. And I still do not feel like I'm really solid on it, but I get it more and more each year.

These statements demonstrate Ms Y as a learner in her classroom as she was looking critically at her current knowledge and beliefs (Novick, 1988). This experience prepares her to deepen her understanding of the content, and revise her ideas as she gathers new information.

Appropriating Salient Features of the Aquarium Hypermedia

When asked about what parts of the Hypermedia she found useful in her own development, Ms. Y felt that working with the same piece of software for 5 years allowed her to incorporate key features within the hypermedia she created. Although her hypermedia does not possess the technological and conceptual sophistication of the aquarium hypermedia, it prepares her for refining her model along a trajectory of increasing expertise (Figures 3 and 4). Moore & Schwartz (1998) suggest that even if students generate representations that are not entirely correct or are faulty, these experiences help them in noticing critical features of experts' representations. This process is important from an actor-oriented transfer framework, as it enables her to see the connections between two situations by identifying the salient features of one learning environment (Lobato, 2002). The excerpts below demonstrate how she is expanding upon her knowledge to integrate important characteristics from the aquarium hypermedia:

I would say that I definitely liked how each question lead to another question because that's how we modeled ours was every question gave an answer but then lead to another question and another question and another question.

The above excerpt highlights a key feature of the aquatic hypermedia of linking different concepts via leading questions. The students can learn about the behaviors and functions of different structures by browsing these questions.

Another important feature of the hypermedia is its presentation. Each section comprises of a brief description accompanied by a visual image. The following excerpt highlights the fact that Ms Y used it as a parameter while constructing her hypermedia:

We also used just short pieces of information because I think the kids get bored if you put too much it's overwhelming. We used pictures and then we also had it not only lead to different the next one and the next one but it bounced back sometimes a design in the hypermedia too.

It is clear that as Ms. Y. identified the relevant features of the aquarium hypermedia. This process of experimentation is also helping her clarify her own thinking (Bransford et al., 1990) about the concepts that she is placing within the new hypermedia contexts. It is notable that she transferred other features of the hypermedia structure beyond SBF, including the use of guiding questions as well as the use of short pieces of text accompanied by simple and relevant graphics.

Appropriating ACT to Model a New System

In addition to appropriating aspects of the Aquarium Hypermedia, Ms. Y also appropriated the ACT program so that students could model body systems in the same fashion as they had for the aquarium system. After students read through the body system hypermedia, they were instructed to develop SBF tables and concept maps using the ACT software (Figures 3 and 4). The following excerpt highlights Ms Y's intentions of evaluating student understanding when placed into the ACT program:

...at first she [PI] came and she was just testing the kids knowledge and that I was not really involved and then we started, actually we started originally started talking about the cell and the

body so that was one of the things then she got the idea of the respiratory system because that was an area she worked in and then she, this slowly develops into you know the NetLogo and the Hypermedia then structure, function, behavior, and I think for me it was all just disjointed all the pieces were here and I was just trying to keep up with her. And then...the ACT program helped a lot because it sort of put everything together for me in the end, like okay, here's all the knowledge that the kids have been getting along the way, here is proof that they got it. And for me it was just a slow process of absorbing everything and you know kind of understanding it until I could you know turn key it and then we could turn around and together make another Hypermedia with it

We think that this exemplifies the importance of the ACT software as a capstone to allow for student understanding of the new system to become explicit. This example from the interview, and the classroom task of modeling body systems in ACT, indicates that Ms. Y possessed the confidence to organize the new ideas generated by her hypermedia into SBF terms using the tool and the importance. Additionally it also highlights her ability to appropriate the ACT tool as the final classroom task to evaluate knowledge generated by the hypermedia as a way to organize student ideas about complex systems.

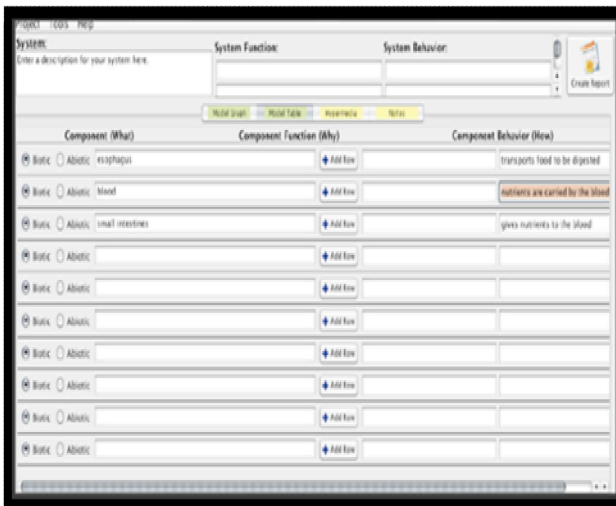


Figure3. Digestive System ACT table view

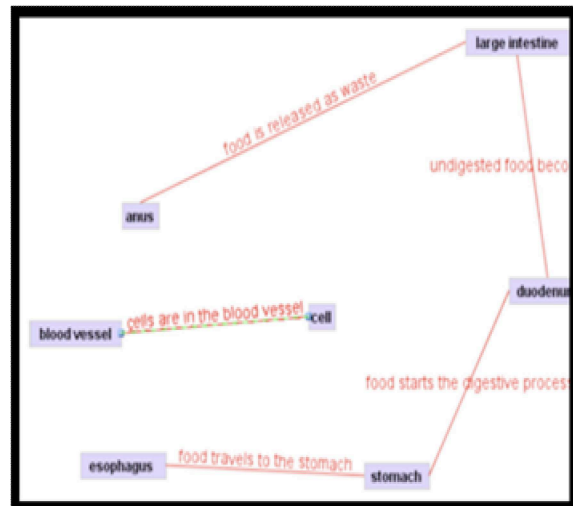


Figure 4 Digestive System Student ACT Model

Discussion

The most relevant contribution our study makes to the current research on alternative approaches to transfer (Lobato, 2004, 2006; Bransford & Schwartz, 1999) is to further expand on the notion of looking at new ways for understanding learning trajectories. As we observed Ms. Y's transition over multiple years our focus was not in assessing mastery over content knowledge but on the processes she adopted during this transition. In terms of learning trajectories, our results highlight the fact that Ms. Y is looking critically at her current knowledge and gradually evolves to an experienced novice within that content area. Data analysis from earlier years reveals an early understanding of the SBF as a conceptual tool. However, she actively sought resources (fellow colleague, Ms. T; project PI; other researchers present in the classroom) to help her understand the interconnections between SBF. Her increasing confidence in the content area, coupled with collaboration, resulted in her being highly motivated to extend the research tools. From a PFL perspective both these processes are vital as she is able to revise her current knowledge and beliefs and it sets the stage for her to analyze and appreciate critical features of the new information presented to her (Bransford et al., 1990; Moore & Schwartz, 1998). This process of analyzing her own beliefs and strategies also targets the active nature of transfer, which is an important part of PFL. The initiative she took in applying her SBF understanding to teaching a new unit demonstrates her ability to revise and rethink the current situation to suit her current goals. Even the hypermedia she created echoes the same pattern of organization as that of the Aquarium Hypermedia. From a PFL perspective this is valuable as it reveals the importance of activities and practices that are beneficial for "extended learning" rather than on one shot task performances (Bransford & Schwartz, 1999). The analysis presented in this study suggests the possibilities of extended research within the field of nontraditional approaches to transfer. In our case, teacher adoption and appropriation of a learning framework was an exciting by-product of scholarly

research because it indicates promising evidence that classroom interventions can be sustained and built upon to be appropriated given specific curricular need. Additionally, our analyses characterize that under the correct conditions, some teachers may be motivated to create their own learning tools when the knowledge is transferred to a new domain, thereby extending the reach of classroom interventions.

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Acknowledgments

This research was funded by IES grant # R305A090210 to the third author. Conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of IES.