Frontline Learning Research
An official journal of EARLI

Frontline **L**earning **R**esearch 1 (2013) 3- 23
ISSN 2295-3159

Conceptual representations for transfer: A case study tracing back and looking forward

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Article received 10 March 2013 / revised 15 May 2013 / accepted 23 May 2013 / available online 27 August 2013

Abstract

A primary goal of instruction is to prepare learners to transfer their knowledge and skills to new contexts, but how far this transfer goes is an open question. In the research reported here, we seek to explain a case of transfer through examining the processes by which a conceptual representation used to reason about complex systems was transferred from one natural system (an aquarium ecosystem) to another natural system (human cells and body systems). In this case study, a teacher was motivated to generalize her understanding of the Structure, Behaviour, and Function (SBF) conceptual representation to modify her classroom instruction and teaching materials for another system. This case of transfer was unexpected and required that we trace back through the video and artefacts collected over several years of this teacher enacting a technology-rich classroom unit organized around this conceptual representation. We provide evidence of transfer using three data sources: (1) artefacts that the teacher created (2) in-depth semi-structured interview data with the teacher about how her understanding of the representation changed over time and (3) video data over multiple years, covering units on the aquatic ecosystem and the new system that the teacher applied the SBF representation to, the cell and body. Borrowing from interactive ethnography, we traced backward from where the teacher showed transfer to understand how she got there. The use of the actor-oriented transfer and preparation for future learning perspectives provided lenses for understanding transfer. Results of this study suggest that identifying similarities under the lens of SBF and using it as a conceptual tool are some primary factors that may have supported transfer.

Keywords: Transfer; Technology; Teacher learning; Systems thinking

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http://dx.doi.org/10.14786/flr.v1i1.1

1. Introduction

The aim of transfer research is to identify instructional conditions that prepare learners to apply what they have learned to new contexts. As designers of learning environments, we seek to create tools to facilitate transfer. We argue that one such tool is the use of conceptual representations to organize instruction by allowing students to develop a means to think about conceptual elements in a more generalised way (Liu & Hmelo-Silver 2009). In addition, our prior research suggests that use of certain conceptual representations can promote understanding of complex systems.

Helping students and their teachers develop an understanding of complex systems is a difficult yet important component of scientific literacy (Sabelli 2006). Given the ubiquity of complex systems in the natural world, transferring ideas about complex system learning in one context to another is critical for the development of scientific thought. In many cases the behaviour of system components can affect its overall function, through emergent processes and localized interactions (Jacobson & Wilensky s2006). These interactions are often dynamic and invisible which make them difficult for learners to understand and present instructional challenges for teachers (Feltovich et al. 2001; Hmelo-Silver et al. 2007).

Here we define systems thinking as being able to understand how bounded phenomena arise through considering the interactions and relationships among these interdependent structures, behaviours, and functions (Hmelo-Silver et al., 2007; NRC, 2012). There is evidence to suggest that students find it especially challenging to think about: (1) the interactions between visible and invisible structures, (2) the effect of their dynamic behaviours on overall functions, and (3) being able to extend their thinking beyond direct causality of complex systems (Grotzer & Bell-Basca 2003; Hogan 2000; Hogan & Fisherkeller 1996; Jacobson & Wilensky, 2006; Leach et al. 1996; Reiner & Eilam 2001).

In the research presented here, we investigate an unexpected case of transfer in a teacher - as the learner - who had been involved in a long-term classroom research project and appropriated the conceptual representation from the researcher-developed units to develop new instruction. This is particularly notable because learning about complex systems is often difficult (Hmelo-Silver et al., 2007).

Although our research focuses on the use of conceptual representations as a tool for learners, it also appears that it can be a tool for teachers to deepen their own understanding of complex systems (Liu & Hmelo-Silver 2009; Goel et al., 1996). Specifically we discuss how Structure-Behaviour-Function (SBF) served as a conceptual representation that promoted transfer across different complex systems (Goel et al., 1996). Structures are defined as the components of a system, behaviours as the mechanisms or processes that occur within a system and functions as system outcomes (Goel et al., 1996; Machamer et al., 2000). We developed technological tools using the SBF representation that make these features of complex systems salient (Hmelo-Silver et al., 2007; Liu & Hmelo-Silver 2009; Vattam et al. 2011). Our study draws attention to a teacher's journey of understanding SBF as a conceptual tool, using it in the context of a technology-intensive science curriculum and her initiative to appropriate SBF as a conceptual representation beyond what we designed it for and use it meet local curricular needs.

2. Research goals

This study focuses on two main research questions:

1. How does a middle school science teacher develop her understanding of SBF as a representational tool?
2. How does generalization of SBF prepare her to make sense of a new complex system?

Specifically the focus of this study is to understand the means by which the teacher takes up opportunities to generalise her understanding of SBF as a representational tool to view similarities between two systems; one provided by researchers and one designated by the teacher. To understand the conditions that facilitated transfer, we need to view it through a lens that magnifies this teacher's learning trajectory. To focus on the dynamic nature of transfer, we did not see a traditional model of transfer as a productive lens. Traditional transfer researchers consider decontextualised expert knowledge, independent of how learners construe meaning in situations (Cobb & Bowers, 1999; Greeno, 1997). Because our objective was to highlight the processes the teacher used to understand and transfer a conceptual representation, we needed to consider alternative transfer models. Such models should illuminate the interactions that were meaningful and engaging for the teacher and subsequently, led her to generalize her learning experience.

2.1 Transfer through alternative lenses

We consider transfer from both an actor oriented approach (AOT; Lobato 2004, 2006) and a preparation for future learning perspective (Bransford & Schwartz 1999) to investigate a teacher as a learner applying knowledge in a new curricular unit. Lobato (2003, 2006) proposes that shifting from the observer's (expert's) perspective to considering how the actor (learner) perceives similarities between the new problem scenarios to prior experiences is a useful tool to understand transfer. Evidence for transfer from this perspective is found by scrutinizing a given activity for any indication of influence from previous activities.

Moreover, we investigate how a greater understanding of SBF representations might have contributed to transfer from a preparation for future learning (PFL; Bransford & Schwartz, 1999) perspective. The PFL perspective focuses on the strategies used by learners in knowledge rich environments and their ability "to learn a second program as a function of their previous experiences" (Bransford & Schwartz, 1999, p. 69). This provides a framework for evaluating the quality of particular kinds of learning experiences and the feedback they provide. Feedback is a powerful factor in preparing students to make sense of instructional materials, to help them in knowledge construction and as a result facilitate transfer of skills needed to unpack novel problems (Moreno, 2004; Tan & Biswas, 2006). Like other alternative perspectives on transfer (e.g., Konkola, Tuomi-Grohn, Lambert, & Ludvigsen, 2007), the classroom context and activity is an important factor in promoting transfer.

We add to the transfer literature by exploring use of the SBF conceptual tool for abstracting systems thinking. That is, the conceptual tool can be used to make sense of complex systems by thinking about macro and micro level connections either independently or at multiple levels of intersections. We make the conjecture that SBF as a conceptual tool can serve as a focusing phenomenon, which makes it suitable for integrating the AOT and PFL lenses of transfer as we describe in the next section. In this study, we investigate how the experiences that led to successful generalization of SBF as a conceptual tool prepared the teacher to keep refining her systems thinking.

2.2 Supporting transfer through focusing phenomena

Lobato et al (2003) propose that *focusing phenomena* supports transfer by prompting students to generalize their learning. As a concept they define focusing phenomena as "observable features of the classroom environment that regularly direct attention to certain mathematical properties or patterns" (p.2). They attribute a combination of factors such as curriculum materials, artefacts, teacher's instructions as important for directing and focusing students' attention towards the intended content. In the context of this study, we extend the notion of focusing phenomena to science.

We propose that SBF serves as *focusing phenomena* (Figure 1) to advance systems thinking. It helps the teacher focus her attention on understanding connections between multiple structures, their functional roles within the complex system and the behaviours they exhibit. Here we consider the importance of generalizing SBF as a tool for transfer.

From an AOT perspective, SBF as a *focusing phenomena* highlights what is similar between two complex systems i.e. the aquatic ecosystem (introduced by the researcher) and human digestive system (introduced by the teacher). It helps concretize the idea that biological systems are similar to ecosystems in terms of interacting at multiple levels. Using this framework affords the teacher opportunities to focus on the connections that exist between various organs of the digestive system. Specifically, it directs the teacher's attention to the ways that "structure and function in biological systems are causally related through behavioural mechanisms" (Hmelo-Silver et al., 2007, p. 308). The teacher's understanding of SBF in the classroom mirrors her understanding of systems thinking. This is important for us, as researchers, as it lets us trace the teacher's learning trajectory. From a PFL perspective, thinking in terms of SBF prepares learners to understand that behaviours are mechanisms and processes that enable structures to achieve their functions in biological systems (Bechtel & Abrahamson, 2005; Machamer, Darden, & Craver, 2000). In the remainder of the paper, we present a case study that considers how several aspects of the learning environment influenced the teacher's generalization of SBF as a conceptual tool.

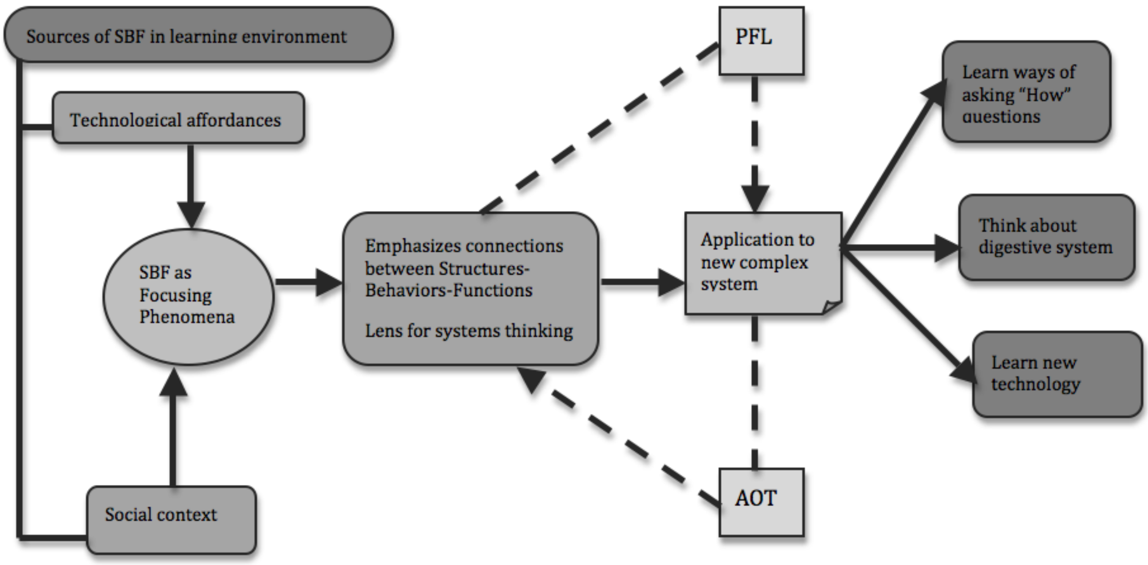

Figure 1. SBF as Focusing Phenomena.

3 A case of transfer: The instructional context

This study is part of a larger research program, which is a technology-intensive curriculum unit centred on an aquarium based aquatic ecosystem. The curriculum provides multiple opportunities for learners to develop and deepen their understanding of SBF as a conceptual tool. First, technological tools such as the RepTools toolkit (Hmelo-Silver et al., 2011) and the Aquarium Construction Toolkit (ACT; Vattam et al., 2011) were designed: (1) to help learners think about aquatic ecosystems in terms of structures, the functions they perform within the system and the behaviours they exhibit to perform the functions, (2) teach about the aquarium ecosystems using SBF as a conceptual tool for a period of 4 years, and (3) engage in active discussions about the concept and ways to teach it with the research team present daily in the classroom and at the annual professional development workshops.

3.1 SBF tools

The RepTools toolkit includes a function-oriented hypermedia (Hmelo-Silver et al., 2007; 2009; Liu & Hmelo-Silver, 2009) organized in terms of SBF representation and Net Logo computer simulations (Wilensky & Reisman, 2006). The hypermedia (Figure 2) introduces the aquarium system with a focus on functions and provides linkages between structural, behavioural and functional levels of aquariums. It is organized around what, how, and why questions which correspond to structures, behaviors, and functions.

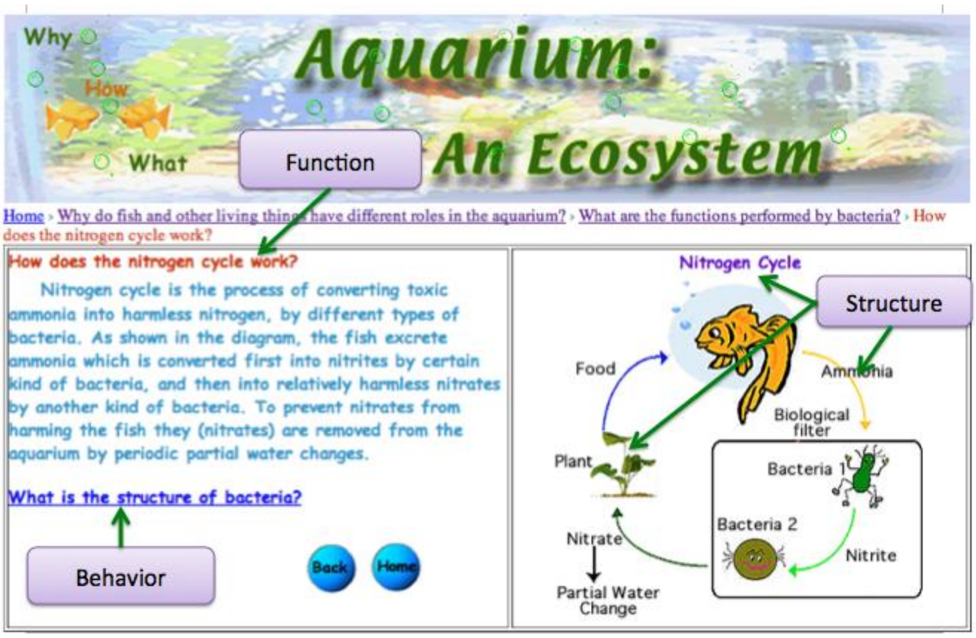

Figure 2. Aquarium Hypermedia.

Two NetLogo simulations allow learners to explore macroscopic processes of fish reproduction (i.e., the *fishspawn* simulation, Figure 3a) as well as microscopic processes (the *nitrification* simulation, Figure 3b) that represent the chemical and biological processes in the aquarium. The simulations provide a context for learners' investigation of the aquatic ecosystem. They afford opportunities for designing experiments, manipulating variables, making predictions, and discussing conflicts between predictions and results. Each simulation allows learners to explore key features that are relevant to the process of fish spawn or nitrification cycle.

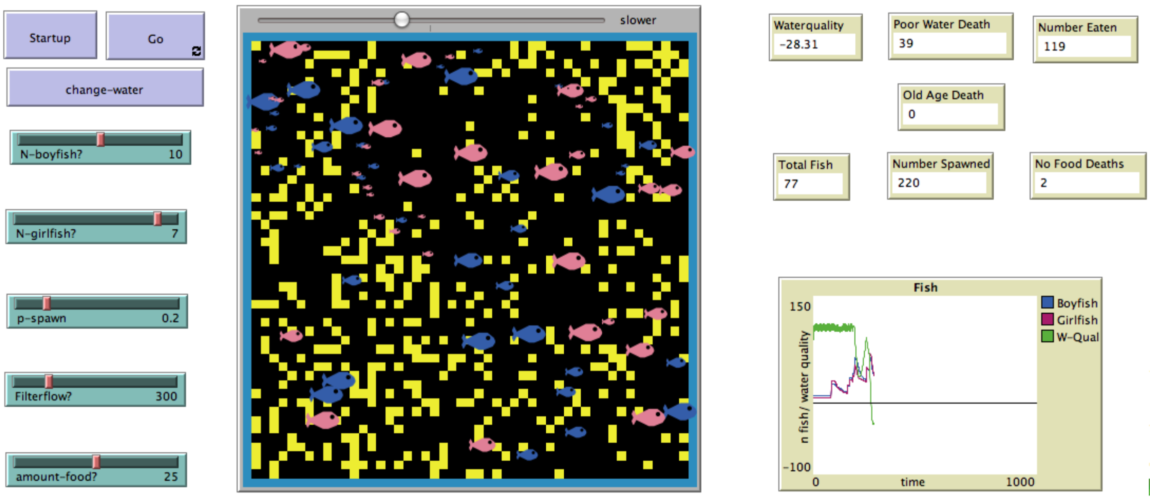

Figure 3a. Macro level- Fish spawn simulation.

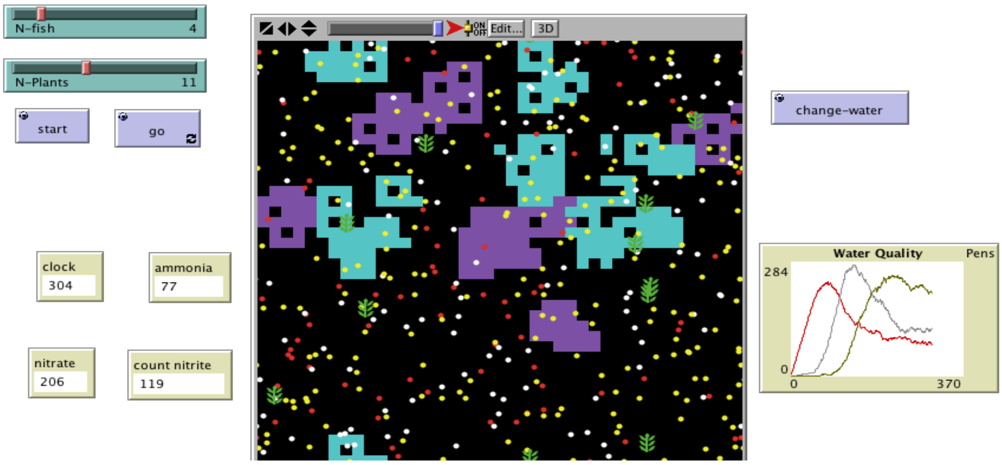

Figure 3b. Micro level – Nitrification simulation.

The second component to the learning environment, ACT is designed to promote construction of SBF models (Vattam et al., 2011). Models can be constructed either in a table (Figure 4a) or graph (Figure 4b) format. The model table focuses learners' attention on thinking about various structures in an ecosystem. The three column table affords the opportunity for learners to think about the structural components, their multiple behaviours and functions. This is valuable because learners get an opportunity to understand both individual mechanisms in the system and the meta-level concepts related to complex systems.

Model Graph | Model Table | Hypermedia | Notes

	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 4a. Sample ACT Model Table.

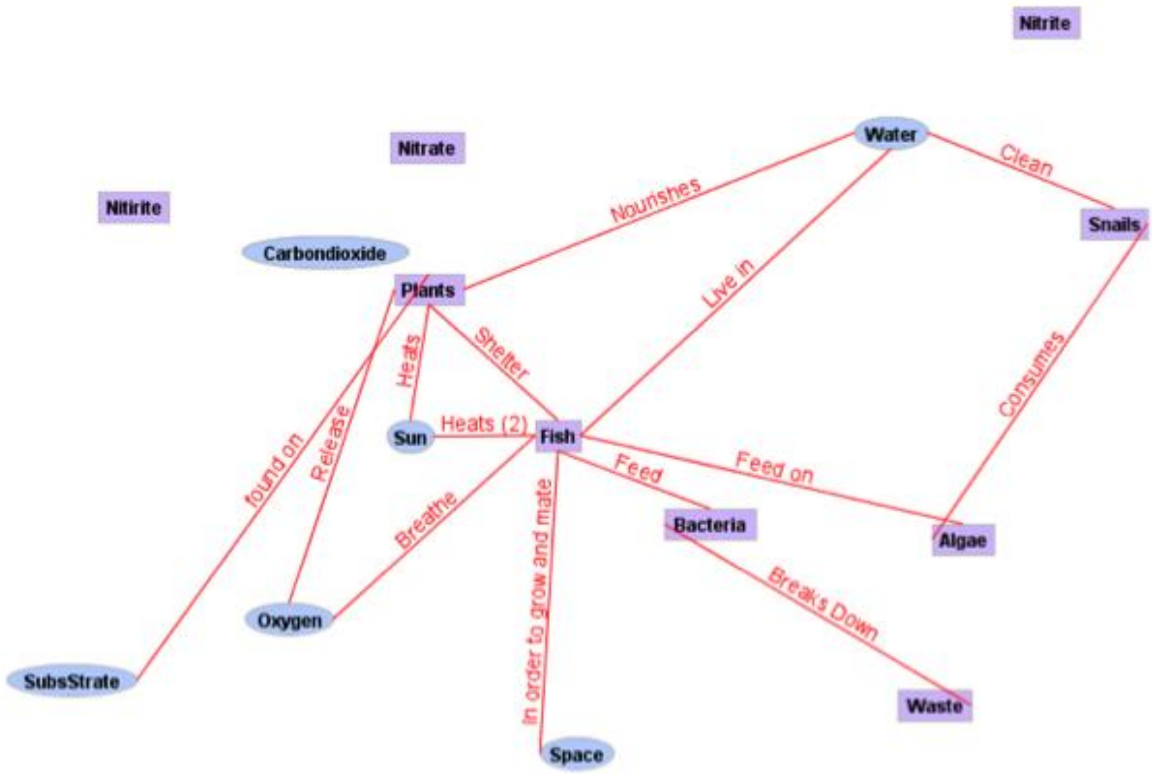

Figure 4b. Sample ACT Model Graph.

The ACT model graph is a platform for learners to create models of their evolving understanding of ecosystem processes in terms of SBF. As students read through the hypermedia, generate and test their hypotheses with the simulations, they integrate the critical structures with their behaviours and functions in ACT models.

3.2 Methods

We used a case study approach to characterize how a science teacher, Ms. Y, appropriated her understanding of SBF as a representational tool and applied it to make sense of a new complex system. Case study methodology allowed us to use multiple data sources to study this complex phenomenon in context (e.g., Stake, 1998; Yin, 2009). Borrowing from interactional ethnography (Castanheira, Green, & Yeager, 2009) we began at the end—the SBF hypermedia that Ms. Y constructed. The unit of analysis for this case is the individual teacher in her classroom context over several years. Through this approach, we used multiple sources of data to trace the social and cognitive events that occurred over time and led Ms. Y to see SBF as a tool she could appropriate for her teaching practice. Although this was not an ethnography we borrowed the logic of this inquiry approach to understand how an individual within a social context constructed particular knowledge over time (Bridges, Botelho, Green, & Chau, 2012).

3.3 Context

Ms. Y taught seventh grade science at a public middle school in North East United States. She had been teaching science for 26 years and had a Bachelor's degree in Elementary Education. This study was part of a larger 4-year study focused on teaching middle school science students about aquatic ecosystems. Ms. Y participated in annual professional development (PD) workshops. The PD focused on concepts related to aquatic ecosystem, analysis in terms of SBF and the technological tools that she would need to use in her classroom. During the PD, Ms. Y. had the chance to share her pedagogical challenges and experiences, such as difficulties in using the software or teaching about SBF as a conceptual tool.

Ms. Y had been using the RepTools and ACT in an aquarium curriculum for four years when she informed us that she wanted to develop her own instructional tools using the SBF representation to teach about cell and human body systems. This prompted her to collaborate with her colleague, another science teacher, Ms. T. Together they used Microsoft Power Point to create a human body system presentation, modelled after the function-centred aquatic hypermedia. We refer to it as the *teacher-created hypermedia*. Given their limitations in terms of technical knowledge in designing a hypermedia similar to the one we had created, the teachers hyperlinked key words in their power point presentation and follow up questions to point to relevant slides.

Ms. T also taught seventh grade science in the same school. She was a new teacher with one year of teaching experience. Ms. T had a science education background. While she collaborated with Ms. Y, she also attended the annual PD and implemented the same technology intensive curriculum on aquatic ecosystem in her classroom.

Each teacher taught four diverse seventh grade classes with approximately twenty-five students in each section. During the curriculum implementation the students were grouped together in small heterogeneous groups.

3.4 Data sources

We had three primary sources of data. First was the artefact that the teacher created (this indeed was the impetus for our research). Second, we conducted an hour-long semi-structured interview with the two teachers, Ms. Y & Ms. T. Finally we collected video data of classroom interactions. These videos were drawn from classroom data from a long-term (i.e., four year) research project. These helped us to understand: (1) why the teacher transferred her generalizations of SBF representations to new instructional domains and (2) how she transferred these understandings. We interviewed Ms. Y & Ms T approximately two months after Ms. Y completed teaching about both 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.

Following Powell, Francisco and Maher’s (2003) recommendations for video analysis, we reviewed video data to identify critical events. In an attempt to trace and track the nature of Ms. Y’s generalizations of SBF we selected representative clips of critical events from her classroom that demonstrated evidence of her developing understanding and generalization of SBF representations as a tool to teach about another complex system. These video clips included whole class discussions that Ms. Y had with her students while: (1) introducing the SBF representation for the aquatic ecosystem in Year 3 (i.e., the year before she created the digestive system unit), (2) introducing the SBF representation for the aquatic ecosystem in Year 4 i.e. the year she employed the digestive system unit, and (3) explanation of SBF representations and modelling of the digestive system unit. We viewed a total of nine clips that consisted of three classroom interactions for each of the three kinds of whole class discussions.

3.5 Analysis

We examined classroom interactions that highlight Ms. Y’s learning trajectory with SBF as a representational tool. The video data were analysed using Interaction Analysis (IA; Jordan & Henderson 1995), which involved collaborative viewing of video clips by six members of the interdisciplinary research team. We successively conducted nine IA sessions to collaboratively review the selected video clips, describe observations, and generate hypotheses. Any differences in opinions were resolved by discussions.

This helped ensure the trustworthiness of our interpretations through the initial independent interpretations of the IA session participants and the subsequent discussions.

During the IA sessions we focused our attention on two specific aspects of Ms Y's practice. First, we paid attention to patterns and variations in the ways that she introduced the SBF as a conceptual tool in relation to the aquatic ecosystem across the four years. Specifically, we examined her explanation of the concept, the analogies she presented and whether or not she sought help from any external resources, such as researchers in the classroom or Ms T.

Second, we focused on how she introduced SBF as a conceptual tool in the context of the human body unit. At this time we made comparisons between the ways the topic was introduced in the aquatic ecosystem with the human body system. We also looked for similarities in terms of analogies. In particular, we wanted to understand if and how her prior knowledge of SBF prepared her to discuss this particular complex system with ease and confidence.

To gain a holistic perspective of the teacher's journey we also examined the interview transcript. We looked for themes related to the mechanisms by which transfer occurred in the ways in which the teacher constructed similarities between aquarium and digestive systems. This allowed us to triangulate the teacher's perspective with the IA and artefact analysis.

4. Findings

Based on our analysis of the interview and video data we identified themes related to AOT or PFL perspectives. These findings helped strengthen our understanding of the processes Ms. Y used to generalize SBF as a representational tool and observe how it prepared her for the transfer. The AOT perspective provided a framework to trace Ms. Y's evolving understanding of using the SBF lens as a tool to make sense of aquatic ecosystem. The PFL perspective demonstrated how Ms. Y transferred and used her knowledge of SBF to make sense of a complex system that was outside the scope of our research.

4.1 Tracing and tracking Ms Y's Understanding of SBF from an AOT lens

4.1.1 Orientation to the SBF representation led by the teacher

Ms Y's journey began with using the ACT tool. The ACT technology enabled construction of SBF representations using the Model Table (Figure 4a). The tool introduced the students and Ms. Y to the language of SBF representations. Initial data analysis of the whole class video revealed that the teacher's introduction of the SBF representation played a critical role in students' conceptual understanding of the complex system. She presented the idea that the SBF representations captured interconnected entities within a complex system while completing the ACT table:

1. Ms. Y**:** Alright, so the first thing yours say is fish right? So, lets go back and tell me what is the behaviour of the fish?
2. Student: Releases waste.
3. Ms Y. OK. So the fish releases waste. Right? Alright, so it, it releases what kind of waste?
4. Students (in unison): Ammonia.
5. Ms. Y**:** Right, so you have that in there right? Now. What is the function?
6. Students (in unison)*:* Remove toxins from the body.
7. Ms. Y: Okay. So we want to get these things out of the fishes' body. Now next, the next one is what?
8. Students: Ammonia.

9. Ms. Y: Ammonia. So, put, put ammonia here. Alright, so now, what is, what is the behaviour of the ammonia? What's it do if you look at it in the tank?
10. Student: Water?
11. Ms. Y: Yeah, it's just floating around right? What's its function do? It's food for bacteria. So it has its purpose right? So the next one on our list which is blank on yours will be what?

In this excerpt, Ms. Y drew the students' attention to the functions and behaviours of various structures present in the aquarium. The students identified structures such as fish (turn 1) and ammonia (turn 8). Next she prompted them to think about their behaviours and functions. In turn 2, the students responded that the behaviour of the fish is to release waste. She pushed them to think in detail about the kind of waste (turn 3) and the function or overall purpose of this behaviour (turn 5). In turn 11, she clearly articulated that structures have a function within complex systems. Although this is a somewhat mechanical application, it also allowed her to begin to see how the SBF lens might serve as a tool for understanding systems.

We speculate that this discussion prepared both the students and Ms Y. to use the SBF conceptual representation to understand the interconnectivity between various structures within complex systems. This initial understanding of SBF as a representation may have prepared Ms. Y to appropriate SBF as tool when she collaborated with her colleague to create a new learning tool i.e. (the teacher-created hypermedia).

4.1.2 Teacher-created hypermedia

Just as the orientation to SBF was the starting point, the artefact that Ms. Y created at the other end bound the case study. Ms Y., in collaboration with her colleague Ms. T, created new hypermedia in the form of an interactive PowerPoint of the cell and body systems mirroring the aquarium hypermedia developed by the research team (Figures 5a and 5b). The teachers' hypermedia outlined the different structures in the system along with orienting *why* and *how* questions. The *how* questions were directed towards behaviours of system components and the *why* questions focused on functions. The teachers created this hypermedia as a learning resource to help students connect cell systems to larger body systems. The research team did not plan either the body system hypermedia or the use of modelling these systems using the ACT software; the teachers did this of their own volition.

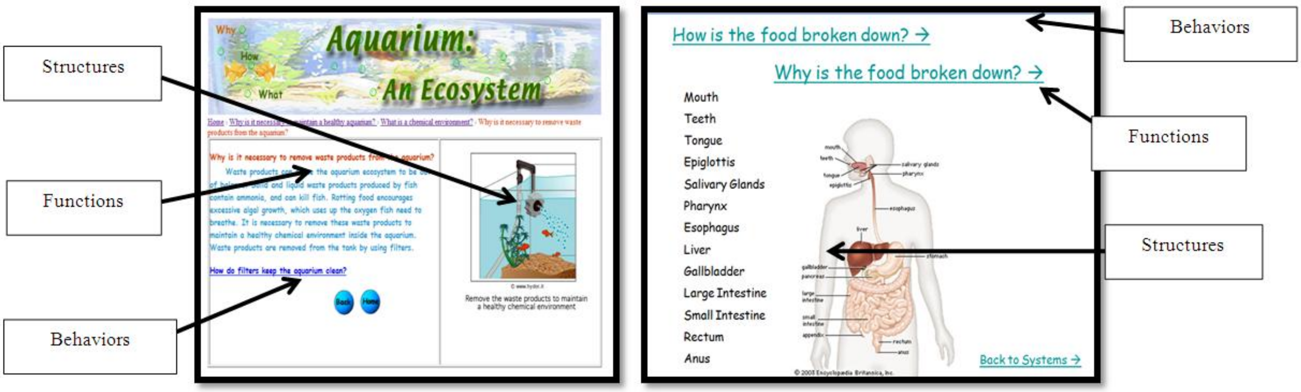

Figure 5a. Researcher-developed hypermedia. *Figure 5b.* Teacher-developed Hypermedia.

The development of the cell hypermedia demonstrated multiple ways by which Ms. Y generalized and transferred her understanding of SBF as a conceptual tool. First, understanding the SBF of the aquatic ecosystem prepared her to teach it better in successive years and second, she was able to modify the learning environment (i.e., by changing them physically–from an aquarium hypermedia to a cell hypermedia and by seeking resources) into something that was more compatible with her current goals.

4.1.3 Identifying similarities through SBF representations

Ms. Y's initiative to extend and appropriate our research and develop additional classroom instruction suggested that the SBF representation was becoming a tool for her to see similarities across complex systems. Adopting an AOT perspective helped us understand how she constructed similarities between what she had been teaching for several years (the aquatic ecosystem) to the current unit she developed (cell and body systems). This perspective helped us recognize which connections she made, on what basis, and how and why those connections were productive (Lobato, 2004). For example, consider Ms. Y's response when asked about the utility of their hypermedia during the interview session:

> 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-...And we're doing the behaviour not only of the cell itself but behaviour of all the systems and then the behaviour of the whole body. And the cells are all part of that whole body.

This highlights that Ms. Y understood that the cells were an integral part of the body systems and could not be taught in isolation. Earlier, she noted that systems in the body are not disconnected and have complex mechanisms that allows for higher order operation. This provided evidence that she now understood how structures within a system perform multiple behaviours in order for it to function effectively. The IA results showed how Ms. Y introduced the SBF representation and refined her thinking over multiple years.

4.1.4 Refining the SBF representation as a conceptual tool

From an AOT perspective we needed to track Ms. Y's transition from her initial naïve ideas about SBF representations to a more expert conception. The results from the IA indicated that Ms. Y's understanding of the SBF representation as a conceptual tool changed. She used several distinct strategies to introduce the topic of complex systems ranging from discrete (i.e., in Years 1, 2 and 3), to acknowledging complexity (in Year 4), and finally providing a systems perspective with her new cell/body unit. In the first three years, she introduced to the SBF representation to her students by mentioning the new terminology being used to understand the aquatic system. However, she introduced structures, behaviours, and functions as discrete constructs. In Year 4, she espoused a coherent view of SBF representation as a conceptual unit. Later that year, while introducing SBF in the context of the unit on cells and body she explained SBF as a system, complete with nested and interconnected subsystems.

4.1.4.1 Year 3: SBF representations

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

> 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 'behaviour'. The behaviour 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 is to start with structure and behaviour. 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 behaviour, and the third column I wrote was function. We're going to start with this second column that is behaviour. When I ask you the behaviour of something, I want to

know is what does it do? "What do fish do?" Swims, eats, breathes, and poops. Okay, all fish swim. That is their behaviour okay. They swim. What else do fish do?

Here Ms. Y. described the meaning of the term “behaviour” somewhat superficially as “what fish do” rather than the more expert mechanistic view. She established linear connections between the structure (fish) and the multiple behaviours (swims, eats, breathes, poops) that this structure exhibits. After promoting an understanding of the behaviour exhibited by the structure (fish), she then drew another relationship between each individual behaviour in the last column to indicate the behaviour’s function.

4.1.4.2 Year 4: SBF representations are interconnected

Over time, Ms Y’s introduction to the SBF representation became richer and more complex. In the excerpt below taken from a whole class discussion in year 4 she described structures, behaviours and functions as interconnected entities within a system, rather than discrete elements on a worksheet:

1. 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. All right, so what does the filter do? What does the filter do? Jim what does the filter do?
2. Jim: Um, cleans out the tank
3. Ms. Y: Cleans the tank. Or cleans the “what part of the tank?”
4. Jim: The water in the tank?
5. Ms. Y: All right, so the filter will clean the water. Okay? Now, why does it clean the water?
6. Jim: So it can put more oxygen into the water?
7. 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…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.]*
8. Pat: Sucking up the water
9. 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?
10. Pat: Well, it has the filter. The filter has like chemicals and stuff.
11. Ms. Y: What do you think is in this bag?
12. Pat: Bad stuff
13. 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 faeces 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, all right so now, why does it clean the water? What is the point of cleaning the water?

After turn 13, the class went on to discuss the fish and the plants, how the filter aerates the tank and how it affects the whole system. In turns 3 and 5 when Ms. Y discussed the behaviours (the mechanism that cleans water in tank) and function of the filter (by collecting faeces from fish) she was guiding students’ answers to structure, behaviour, and function simultaneously and filling in the chart appropriately, stressing relationships rather than focusing on any one aspect in isolation. Turns 6-12 show that Ms. Y used student response to generate more questions that linked what and why questions throughout her classroom discussion, highlighting the system complexity.

4.1.4.3 Year 4: SBF representations at multiple levels of complex systems

Later in the same year, when introducing her unit on the cells to the class, Ms Y emphasized that SBF works as a whole across multiple levels of complex systems. As the next excerpt shows, she did so not directly, but more discretely through leading questions:

1. 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 modelling to the other body systems? Because you also want to go and look at the function. What do you think?
2. Lucia: Umm, what about if you like umm put a picture of the cell.
3. 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…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? …

These demonstrate how Ms. Y refined her thinking about SBF as a conceptual tool. Whereas earlier, her focus was primarily in working with the aquatic ecosystem, she later introduced a new level of complexity by introducing the idea that there exists multiple 'mini systems' within the human body system. She still focused largely on structures but she also made connections to behaviours and functions. In addition, she helped students understand that one structure may have multiple behaviours and functions (in turns 1 and 3).

Comparing her SBF representation of the cell system here to that of the aquatic ecosystem in the earlier unit, she presented it to the class as a coherent system rather than discrete SBFs. In addition, when applying the SBF representation to the cell, Ms. Y introduced a meta-perspective by explicitly explaining that the task was to represent their ideas through modelling (in turn 1). Moving away from the isolated task provided in earlier (i.e., filling out the table by first listing structure followed by behaviour, and then function), Ms. Y explained that the students were organizing their knowledge in model graph. By placing emphasis on the modelling tool and providing students with the starting point of the structure, the cell, Ms. Y explained that the task was 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 representation in the aquarium unit.

This transition suggested that Ms. Y was an active learner herself. She frequently asked questions to the research team and Ms. T, to refine her understanding. This practice of asking questions had two effects. First, it helped Ms. Y identify and address the gaps in her understanding, which prepared her for future learning. Second, it shed light on the processes that she as an actor (learner) used to construct similarities between the aquatic ecosystem and cell system.

4.2 Experiences to promote transfer from a PFL perspective

4.2.1 Recognition of teacher as a learner

In the interview, Ms. Y indicated that since the beginning of her involvement in the project, her knowledge 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 became more competent in this role. In the interview, she acknowledged her lack of mastery over the content and was aware that she refined her ideas of the SBF representation and the aquarium unit which lead to development of the new unit:

> Okay, my knowledge of this still develops every year because it's knowledge that [research team leader] 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 [research team leader], 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 demonstrated that Ms. Y saw herself as a learner in her classroom as she was looking critically at her current knowledge and beliefs. This experience prepared her to deepen her understanding of the content, and revise her ideas as she gathered new information.

4.2.2 Collaboration facilitates generalisation

The collaboration aspect was beneficial during the inception, design, and construction of the teacher created hypermedia. Together they went beyond our research agenda by using SBF as a conceptual tool to create a power point presentation of human body systems. It afforded opportunities for sense making and focus on critical aspects of complex systems while working with the tools (Figure 6). As Ms. Y talked about the creation of the cell hypermedia, she revealed that she was highly motivated to do so because of the potential for feedback and interaction with Ms. T. For example, when asked how the idea came about and the variables that affected the development of the new tool, Ms. Y responded:

> So then I kind of realized that what I needed to do was give her [Ms. T.] my idea and then hear from her what she would add to that and in turn that would- I would take what she added into my lesson, so one of us throws out like a main idea and then the other one builds upon that main idea and then we get a better idea. And that's how I think that the Hypermedia came along. Because this whole concept has been in my head for a long time, about how kids don't understand the whole body and the cells connection to the body. So I talked about it with Ms. T and then she started talking about making a Hypermedia and then we went back and forth on how we we're going to do it.

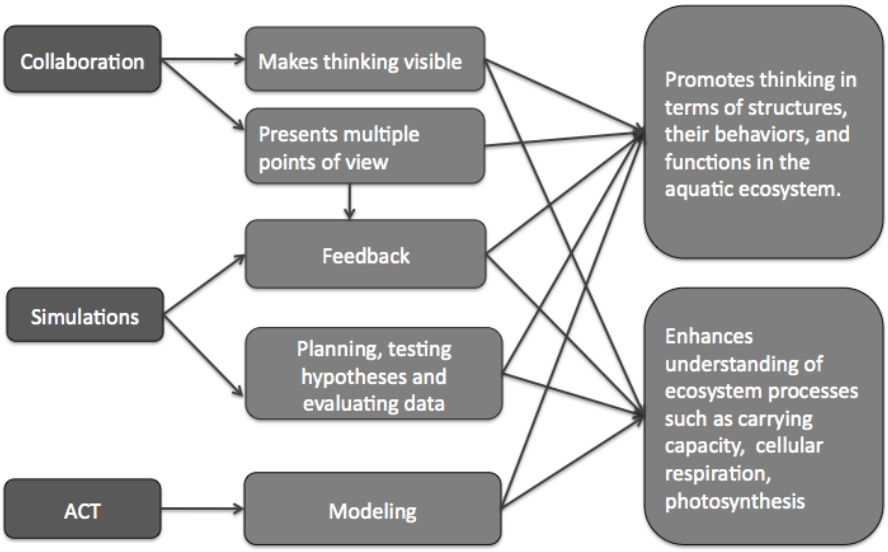

Figure 6. Affordances of the learning environment that promote SBF thinking.

From a PFL perspective, people seeking multiple viewpoints about issues may be one of the most important ways to prepare them for future learning (Bransford & Schwartz, 1999). It is clear from this excerpt that Ms. Y. felt it useful that she could exchange her ideas and collaborate in the creation of the new hypermedia with Ms. T.

This finding suggests that Ms. Y. was able to see the possibilities for transferring her understanding of the SBF representation. However, this transfer was dependent on the idea of using hypermedia itself as a way to organize complex content in addition to the SBF representations. Our next set of results focus on elaborating how she used the aquatic hypermedia to guide her thinking about designing for another complex system.

4.2.3 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 Aquarium Hypermedia for four years allowed her to incorporate some of the key features in the hypermedia she created. Although her hypermedia did not possess the technological and conceptual sophistication of the aquarium hypermedia, it prepared her for refining her understanding along a trajectory of increasing expertise. This process was important from an AOT perspective as it enabled her to see the connections between two situations by identifying the salient features from the earlier hypermedia environment (Lobato, 2004). 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:

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

From the interview it is clear that Ms. Y drew upon relevant features of the aquarium hypermedia. Although her rationale for keeping a short text was different from what we had in mind while designing the aquarium hypermedia, this process of experimentation also helped her clarify her own thinking about the concepts that she is placing within the new hypermedia contexts (Bransford et al., 1990).

4.2.4 Approaching ACT to model a new system

In addition to appropriating aspects of the Aquarium Hypermedia, Ms. Y also appropriated the ACT tool so that students could model body systems in the same fashion as they had for the aquarium system (Figures 7a and 7b).

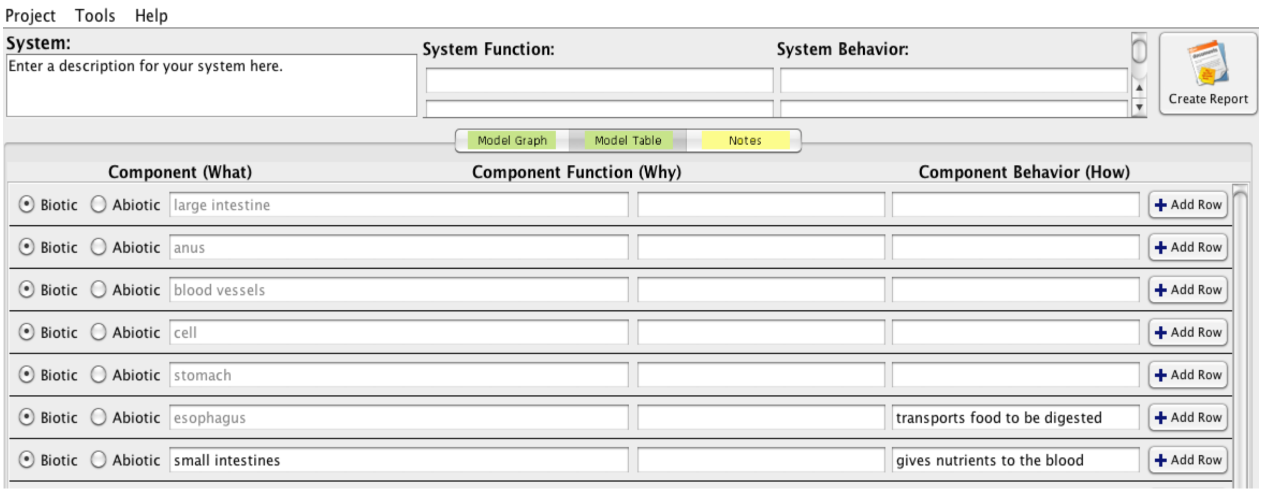

Figure 7a. Digestive system ACT Table view.

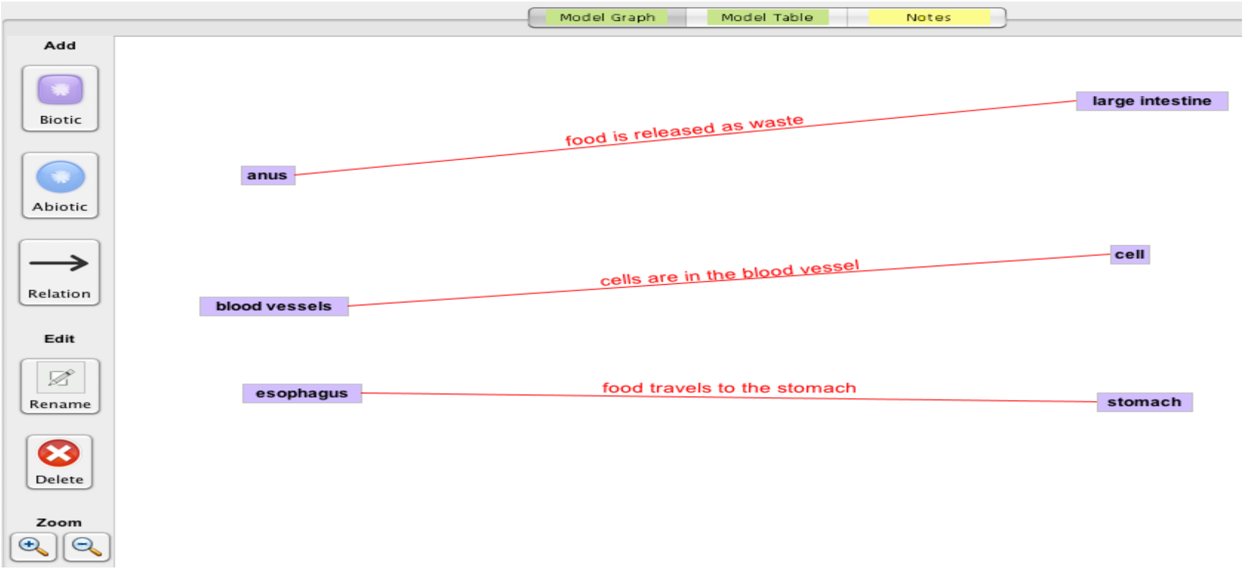

Figure 7b. Digestive system ACT Graph view.

The following excerpt highlights Ms.Y's journey of trying to understand how to use SBF as a conceptual tool, the ACT technology itself and feel comfortable using it to teach by herself:

> At first she (research team leader) came and she was just testing the kids' knowledge and that I was not really involved. And then … we originally started talking about the cell and the body as that was an area she worked in, and then she got the idea of the respiratory system because that slowly developed into … the Net Logo and the Hypermedia. Back then structure, function and behaviour I think for me 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 turnkey it and then we could turn around and together make another Hypermedia with it.

This exemplified the importance of the ACT software as a capstone to allow for students' and Ms. Y's understanding of the new system be made explicit. In the interview Ms. Y recalled that in the beginning of the research program (i.e., Years 1 and 2), her understanding of the framework was "disjointed". She attributed the ACT modelling toolkit to prepare her to create the human body system hypermedia. It appeared to help her think about interconnections between structures, their functions and visible behaviours. This example from the interview, and the classroom task of modelling body systems in ACT, indicated 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 highlighted 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.

4.2.5 Preparing to ask SBF oriented questions

A critical aspect of transfer of the SBF framework involved being able to make sense of the new complex system in terms of "what", "how" and "why" questions. The ACT modelling table (see Figure 4a) prepared learners to think about the aquatic ecosystem in terms of SBF by answering questions related to "what", "how" and "why." It was evident that questions related to "what" pertain to visible and invisible structures that determine key variables of the aquatic ecosystem. Because the learner had to only identify relevant components in the first column, it involved an important but superficial level of system understanding, unless it led the learner to consider why and how it performs specific actions in context to the aquatic ecosystem.

Video analysis in Year 1 revealed that although Ms. Y discussed the role of functions and behaviours, she was more comfortable labelling the aquatic ecosystem in terms of its relevant components. This was apparent, as she would begin the class with "what" questions. If the students gave her the expected answer she would make an attempt to elaborate on it. But when the students gave incorrect answers, she just ignored the response. As a result the students were not encouraged to share their confusion with the class in terms of why they thought so and how they came to the conclusion. During the year we observed that Ms. Y consistently asked more "what" questions. This prompted the students to give single word responses. The students also noticed that the teacher expected them to give short answers that did not call for detailed explanations. This indicated that Ms. Y was hesitant to open the discussion for an in-depth systems thinking conversation that focused on SBF relations. It was likely that at that stage her idea about complex systems was focused on identifying relevant structures.

We observed a slightly different trend in Year 2. Although the "what" questions dominated the whole class discussions, students were also asked to think about possible interactions or connections between structures. As the students identified such relationships, Ms. Y led the discussion on “how” questions by writing down behaviours that connected structures.

Video analysis indicated that in years 3 and 4, Ms. Y appeared to be confident in discussing the aquatic ecosystem in terms of a complex system, interconnected by visible and invisible components as this next example shows:

1. Ms. Y: Yes, anybody have something else, let’s put another living thing in there. What do you have?
2. Jaden: Microorganisms.
3. Ms. Y: Okay. So what are microorganisms?
4. Jaden: They clean up the waste.
5. Ms. Y: What do you mean they clean up waste?
6. Jaden: They eat.
7. Ms. Y: Ok, the next problem is function. These particular structures do a particular behaviour and that behaviour fits in a little bit more into the whole picture. Think why does it need to do this behaviour for it, why do the fish need to swim?

This excerpt shows that Ms. Y opened the discussion by asking the class to identify structures connected to the aquatic ecosystem. Next she drew their attention to thinking about their behaviours. As soon as the class discussed some behaviours, she asked them to think about behaviours in context to their functional role in the aquarium based aquatic ecosystem. Ms. Y was able to build upon her prior understanding of SBF as a conceptual tool.

5. Discussion

As we seek to understand transfer, we must address questions related to the “what” and “how” of transfer. That is, we need to articulate the exact nature of the content or “what” is being transferred. Equally important is identifying the mechanisms or the “how” that is responsible for this transfer to occur. We suggest that we can accomplish these goals through the integration of AOT and PFL perspectives on transfer. We used AOT to reach backwards and see how the similarities were constructed, whereas PFL allowed a look forward at how applying SBF prepared Ms. Y for her future learning and practice. The case study findings showcase how different perspectives on transfer allowed us to understand how participation in a research project driven by principles of learning empowered a teacher to appropriate these tools in her own practice, going beyond the research project context.

This case study suggests that SBF as a conceptual tool has potential for making sense of complex systems. We propose that using SBF as a *focusing phenomena* (Lobato et al., 2003) is a mechanism that facilitates transfer. SBF was a lens through which Ms. Y could see the relationship between systems and prepare her to learn about new systems. Our findings demonstrated the processes adopted by the teacher to generalize her understanding of SBF. This included an initial superficial engagement with SBF that she deepened and refined over several years and her own reflectiveness in seeing herself as a learner. In addition we discussed the influence of the social environment and technological affordances that appear to prepare her for transfer. The additional viewpoints of Ms. T. and the conversations with the research team suggest that collaboration is important in preparing for transfer. Having a general-purpose tool that she could re-purpose to use for a new unit was instrumental in this process. Finally, she was able to use the hypermedia that the research team had created as a worked example that allowed her to explore the content and how SBF could be applied to a new domain.

From a PFL perspective, these results shed light on specific processes and challenges that Ms. Y had to overcome. Specifically we were keen to understand what it took for a teacher to acquire mastery over using a conceptual tool in one context and be prepared to use it to solve a problem in a different context. The findings indicate that the SBF representation focused the teachers' attention on the behavioural connections and functional roles of components within complex systems. It prepared them to think about the actions or "how" components behave within a complex system in relation to their overall functions. Both teachers reported that this was useful when they started working on creating the hypermedia on digestive system.

Although the teacher-constructed hypermedia lacked the technical sophistication of the researcher created hypermedia, the teachers made productive use of a technology they were familiar with, a power point presentation. The teachers also successfully incorporated key features of the aquarium hypermedia such as leading questions, short descriptions and use of images. Their interview responses indicated that their prior experience with the aquarium hypermedia drew their attention to these features. This prepared them to be efficient and effective with their own hypermedia design. Both these processes (i.e., creation of the new hypermedia and thinking in terms of behaviours, in addition to structures and functions) were vital as Ms. Y was able to revise her knowledge and beliefs, which set the stage for her to analyse and appreciate critical features of the new information presented to her (Bransford et al. 1990; Moore & Schwartz, 1998). This process of analysing her beliefs and strategies also highlights the active nature of transfer, which is an important part of PFL. The initiative she took in applying her SBF representation understanding to teaching a new unit demonstrates her ability to revise and rethink the current situation to suit her current goals. 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).

Our study also extends the transfer literature by proposing new ways for understanding teacher learning trajectories. As we observed Ms. Y's transition over multiple years, our focus was on the processes she followed during this transition rather than assessing mastery over content knowledge. In terms of learning trajectories, our results highlight the fact that Ms. Y was looking critically at her knowledge and gradually developed a deeper understanding in that content area. Data analysis from earlier years revealed a limited understanding of the SBF representation as a conceptual tool. However, she actively sought resources (fellow colleague, Ms. T and researchers present in the classroom) to help her understand the interconnections between multiple structures, their functions in the system and visible and invisible behaviours. Her increasing confidence in the content area, coupled with collaboration, resulted in her being highly motivated to extend the research tools to other areas of her classroom practice.

This case study provides an existence proof that AOT and PFL can be used to explain a single case of transfer. It is important however to consider the limitations from a single case (Yin, 2009). Although we cannot rule out all possible rival explanations, we triangulated data from multiple data sources and included researchers with a range of disciplinary backgrounds and experience in the interaction analysis. Other members of the research team who were not involved in the IA sessions reviewed the examples and interpretations that were presented here. We acknowledge that further research in complex classroom environments is needed in order to generalize these findings. Because of the importance of the social interactions and feedback that Ms. Y received from teaching her students (e.g., Okita & Schwartz, in press), it is unlikely that a purely cognitive explanation could account for these results.

The analysis presented in this study suggests the possibilities of extending research on alternative approaches to transfer (Lobato, 2006; Bransford & Schwartz, 1999; Van Oers, 1998). These new approaches to transfer suggest a much more complex and dynamic process than traditional cognitive accounts. Our results also suggest that different theoretical frameworks can be productively integrated in providing accounts of transfer. In our case, teacher adoption and appropriation of a learning framework was an exciting by-product of scholarly research because it provides evidence that classroom innovations can be appropriated and sustained.

Keypoints

- SBF as a focusing phenomena is a mechanism that facilitates transfer. It acts as a lens through which the learner can see the relationship between systems and prepare them to learn about new systems.
- There are possibilities of extending research on alternative approaches to transfer (Lobato, 2006; Bransford & Schwartz, 1999; Van Oers, 1998). These new approaches to transfer suggest a much more complex and dynamic process than traditional cognitive accounts. Different theoretical frameworks can be productively integrated in providing accounts of transfer.

Acknowledgements

This research was funded by Institute of Education Sciences (IES) grant # R305A090210. Conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of IES. We thank the participating teachers without whom this work would not be possible. An earlier version of this research was presented at the 2010 International Conference of the Learning Sciences.

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