# Effects of Conceptual Representation on Learning from Hypermedia

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**Abstract:** Studying complex systems is increasingly important in many domains. Several features shared by complex systems hinder deep understanding. For example, understanding complex systems involves thinking about multiple interdependent levels, non-linear causality and/or emergence. Conceptual representations offer opportunities to become integrating frameworks across different domains. This study investigates how alternative conceptual representations embodied in hypermedia can help middle school students better understand a complex system, the human respiratory system. We designed two versions of instructional hypermedia based on structure-behavior-function theory. SBF is a conceptual representation that is part of the disciplinary toolbox of biologists and thus is an appropriate representation for learning in this domain. One hypermedia was function-centered while the other was structure-centered. We contrasted the instructional effects of these two alternative conceptual representations. Students using the function-centered hypermedia developed deeper understanding than those using the structure-centered version on one of the two measures. Implications and limitations are discussed.

## Introduction

Complex systems have the potential to be a unifying framework across many aspects of science education (Jacobson & Wilensky, in press). However, such systems have many characteristics that make them difficult to understand. They tend to be hierarchically organized and are comprised of multiple interdependent levels (Wilensky & Resnick, 1999). Moreover, the whole nature of the system cannot be predicted from isolated parts but occurs through their interactions (Hmelo-Silver & Azevedo, in press). These characteristics make them difficult for students to understand (Feltovich, Coulson, & Spiro, 2001; Wilensky & Resnick, 1999).

Hypermedia has been used to teach about complex systems (e.g., Azevedo, Cromley, & Seibert, 2004; Jacobson & Archodidou, 2000). Jacobson & Archodidou (2000) demonstrated that hypermedia could support problem-centered learning about complex systems using design elements based on learning sciences principles. They addressed the representational affordances of hypermedia in varied forms such as text, pictures, and digital video, animations. Azevedo, Cromley, & Seibert (2004) examined the role of self-regulated learning in learning from a complex systems hypermedia. Their study investigated various types of scaffolding techniques on supporting learning of complex topics with hypermedia. However, little research has been done to examine the role of conceptual representations underlying hypermedia. The study is an attempt to fill this gap and investigate how alternative conceptual representations embodied in hypermedia can help middle school students better understand a complex system, the human respiratory system. In particular, we contrasted two alternative SBF conceptual representations by asking students using two different versions of hypermedia to learn about the human respiratory system.

### Obstacles to Learning about Complex Systems

Novices in a domain find complex systems difficult to understand (Hmelo-Silver & Pfeffer, 2004, Hmelo-Silver, Marathe, & Liu, 2004; Marathe, Liu, & Hmelo-Silver, 2004; Jacobson, 2001). Thinking about complex systems is often counterintuitive and taxes working memory resources (Feltovich, Coulson, & Spiro, 2001; Narayanan & Hegarty, 1998). Novices have a piecemeal understanding of complex systems because education about complex phenomena often ignores the phenomena themselves and instead has learners focus on memorizing the names of the parts of the system (AAAS, n.d.). Thus, it is not surprising that most people understand complex systems as collections of parts with little understanding of the multiple levels and interdependencies with the system (Hmelo-Silver & Pfeffer, 2004; Hmelo-Silver et al., 2004).

In general, novices tend to focus on superficial details and have difficulty seeing the underlying principles that are visible to experts, and complex systems are no exception (Chi, Feltovich, & Glaser, 1981). Previous research has shown that novices tend to think about the human respiratory system and the aquarium system as composed of isolated structures whereas experts tend to integrate behavioral and functional perspectives of the composed elements in the systems (Hmelo-Silver et al., 2004; Hmelo-Silver & Pfeffer, 2004). We also found that novices focus on perceptually salient macroscopic phenomena (e.g., lungs, rib) in the human respiratory system, whereas experts went beyond the visible structures and consider the invisible and microscopic phenomena (e.g., diffusion, cellular respiration). The results suggest that experts use a structure-behavior-function conceptual representation for reasoning and that these conceptual representations play an important cognitive function in building a deep understanding of complex systems. It is, however, always implicit in many learning resources.

In order to facilitate students to learn about complex systems, it is necessary to provide artifacts that use appropriate conceptual representations that are consistent with how experts understand and reason in the domain. Previous research (Hmelo-Silver et al., 2004) led us to hypothesize that SBF is such a conceptual representation. It can be embodied by hypermedia to mediate student understanding. We hypothesize that alternative conceptual representations, underlying different versions of the hypermedia, might lead to differences in learning processes as well as outcomes.

## SBF Conceptual Representation Embodied in Hypermedia

Hypermedia uses varieties of media, such as diagrams, text, and animation, to represent knowledge systems in a non-linear fashion. In addition to concrete representations, such as diagrams, hypermedia can also embody conceptual representations thus help learners to think more like "experts". Some research has investigated the relation between hypermedia, conceptual representations, and cognitive models (Eklund, 1995; Jacobson, Maouri, Mishra, & Kolar, 1996; Jonassen, 1992). For example, Eklund (1995) suggested that if learning is facilitated by the formation of node-linked structures in the learner's cognitive model, it was possible to maximize learning in hypermedia by using an expert's construction of the domain to form the basis for the creation of nodes and links. Jacobson, Maouri, Mishra, and Kolar (1996) claimed that non-experts lacked an interconnected understanding of the deep structure of knowledge, thus hypermedia should embed explicit cognitive modeling to facilitate student learning. The fundamental assumption is that the conceptual representation underlying hypermedia can map fairly well to human knowledge structures and facilitate learning. Our assumption is that if the underlying conceptual representation of hypermedia can make the expert models of how they organize and solve problems overt and tangible to students, it can help students organize knowledge in an efficient way and build a deep understanding. In this study, we use a structure-behavior-function (SBF) representation to frame the knowledge structures in the domain of the human respiratory system (Goel et al., 1996). This representation is effective for reasoning about complex systems, as the expert-novice studies demonstrated, and is a cultural tool for reasoning in the biological sciences (e.g., Tabak & Baumgartner, 2004). In the SBF representation, structure refers to the elements that comprise a system, such as lungs, alveoli, ribs, and diaphragm. Behavior refers to how these elements operate and coordinate to make the system work as a whole. For example, the blood carries oxygen and carbon dioxide in capillaries to conduct the gas exchange with the gas in alveoli. Functions refer to the roles of each element in the system as well as the role of the whole system. For example, the function of alveoli is to provide enough surface area for gas exchange in the respiratory system.

The navigation sequence in hypermedia can guide students' thinking by making the SBF conceptual representation explicit. For example, in order to foreground function, the links in the hypermedia can lead students to first explore the functional aspects of the system and only later the structural aspects. So for the respiratory system, a functional orientation might lead students to explore why we need oxygen and then how we transport it and finally, the structures that are used to accomplish this. A structural orientation would do the opposite.

For this research, we designed two versions of the hypermedia system to embody two alternative conceptual representations. Since our interest lies in investigating the role of conceptual representations, we controlled the content and amount of information in both versions so that the only difference was in the underlying conceptual representation that is used to organize the navigation pages in hypermedia (Figure 1). We used the organizational structure of the hypermedia to guide students' explorations. However, the students were instructed to freely explore the hypermedia pages. The observation during the experiments showed that most students followed the expected navigation sequence in both conditions. The Function-centered hypermedia embodied a function-oriented conceptual representation by stressing information about how the system works and how parts of the system behave and interrelate with each other. The navigation sequence generally moves from functional information to behavioral and finally to the structural. In order to do that, we designed two big functional questions on the main navigation page: "Why do we need oxygen?" and "How does oxygen get into our body?" Clicking on the links from the two questions led students to the functional aspects of the system, such as cellular respiration and diffusion. Then the links on the functional pages led the students to the behaviors and the links on the behavioral pages to the structures. In contrast, the structure-centered hypermedia sequence was generally ordered from the structural knowledge to the behavioral and finally to the functional. In a manner similar to most traditional textbooks (AAAS, n.d.), the structure-centered hypermedia uses a conceptual representation that emphasizes the structures that compose the system. The main page of the structure-centered hypermedia displays a diagram with all the structures labeled and linked to respective structures, then the behaviors and finally the function. They can then explore behavioral and functional aspects of those structures. In summary the two versions of hypermedia embody two alternative conceptual representations of the human respiratory system, namely a function-centered versus a structure-centered representation.


Figure 1. Opening screens of F and S hypermedia.

# Method

## Participants

Forty-two seventh grade students from a suburban public middle school volunteered to participate in this study. They were from two classes taught by one teacher and were randomly assigned to one of the two conditions: the function-centered condition (F-hypermedia) and the structure-centered condition (S-hypermedia).

## Materials

We designed two versions of hypermedia for students to learn about the human respiratory system: the function-centered (F-) and structure-centered (S)- hypermedia. The only difference across the two conditions was the version of hypermedia they used to learn about the human respiratory system. The content of both hypermedia systems was strictly controlled. Both shared the same information and most pages were the same in both versions. The major difference between these two versions of hypermedia was in their underlying organization framework, which embodied different conceptual representations. In the F-hypermedia, the embodied conceptual representation was function-oriented. That is, the organization of the hypermedia system was on functions of the system. In contrast, the organization of the S-hypermedia was on the structures, as described above. In addition, another purpose of the two versions of hypermedia was to use the embedded navigation sequence in the hypermedia to influence students' exploration sequence. Students using the F-hypermedia began their exploration with two big functional and behavioral questions (see in Figure 1), which led them to the functions and behaviors of the system. Then they would explore the respective names of the parts. On the other hand, students using the S-hypermedia began their navigation from a diagram with labels of the structures of the system.

## Procedure

The study was conducted in a lab at the middle school using laptop computers. Half the laptops displayed the main page of the F-hypermedia and the other half displayed the main page of the S-hypermedia. Students explored the hypermedia for about 40 minutes. Later that week, students completed a written posttest to assess their understanding of the respiratory system. The posttest asked students to draw the system and answer a number of open-ended questions.

## Coding and Analyses

In order to contrast the different effects of alternative conceptual representations on student learning about the human respiratory system, we conducted two levels of coding on the post-test: a mental model analysis and an SBF analysis. All the coding was conducted blind to condition. In both analyses, one primary researcher conducted the majority of the coding and a second independent rater coded 20% of the posttests. The inter-rater agreement was above 90% in both cases.

The SBF analysis used a fine-grained coding to assess the students understanding in terms of SBF. Any mention of parts of the system, such as lungs, ribs, was coded as a structure, mention of mechanisms were coded as behaviors, and mention of roles in the system as function (see Hmelo, Holton, & Kolodner, 2000 for details). In addition, we divided the components of the human respiratory system into the salient and nonsalient levels. The salient level includes understanding of macro level phenomena involved with external respiration, such as airways, brain, diaphragm, heart, lungs, muscles, ribs, which are surface organs noticeable to students. The nonsalient level includes understanding of micro level phenomena related to gas exchange, transport, and internal respiration, such as alveoli, blood, capillaries, cellular respiration, red blood cells, vascular system. The mental model coding attempted to capture the holistic level of the student's understanding after using the hypermedia. Based on previous research (Hmelo-Silver, Marathe, & Liu, 2004), we identified five categories of mental models of the human respiratory system as shown in Table 1. The models progress from simple, structure-based models to more elaborate, interconnected models that consider behaviors and functions.

Table 1. Human respiratory system mental models.

| Mental Model | Description |
|---|---|
| Egocentric | Limited understanding of the structures involved. These structures are thought to exist independently and their connections are not understood. The person also thinks of his/her own lungs as central. |
| Simple Healthy Lung | Lungs are regarded as central but the model also has a limited understanding of other structures like heart, diaphragm and ribs. Though the person understands that the other organs influence lungs, the functional relationships are not understood. |
| Healthy Body | Understanding centered on the respiratory system as a whole. There is some understanding of the functional and behavioral interdependence and interactions between different structures. |
| Pragmatic | An expert view with elaborate systemic structure, behavior and functional connections. The lungs are central and the other knowledge radiates outwards from them. |
| Hierarchical | An expert view with elaborate systemic structure, behavior and functional connections. There is an understanding of the centrality of controlling mechanisms (e.g. regulation by brain) for the proper functioning of the respiratory system. |

## Results

We hypothesized that there would be differences across conditions, particularly in behaviors and functions. Secondly, we hypothesized that the F-hypermedia would help students understand the nonsalient phenomena better than the S-hypermedia because the nonsalient phenomena are critical for understanding the ultimate function of the system—to provide oxygen for cellular metabolism and remove waste products. Finally, we hypothesized that there would be difference across conditions in the level of mental model. We summarize the findings here, each statistically reliable at the $p < .05$ level.

A Chi square test was conducted to compare the mental model levels across conditions. Among the total 41 students, 13 students' mental models were identified as the egocentric level, 22 as the simple healthy lung level, and 6 as the healthy body level. None of them reached the fourth and fifth level. We did not any find differences for the mental model ($\chi^2$ (1, 39)= .72) analysis across conditions. In both conditions, the majority distribution of students' mental models remained at the low levels (the egocentric and the simple healthy lung level) after using the hypermedia intervention. ANOVA tests followed to compare the SBF concepts understanding using types of hypermedia as the independent variable and structures, behaviors and functions as dependent variables. As shown in Table 2, an ANOVA demonstrated that the students using the F-hypermedia identified more behaviors than the S-hypermedia groups ($F$ (1,39)=8.30, $p$<. 05) and a trend towards more functions ($F$ (1,39)=3.72. $p$=. 06). There was no difference for structures.

Table 2. Means and standard deviations of total SBF by hypermedia type.

| Group | N | Structure | Behavior | Function |
|---|---|---|---|---|
| F-hypermedia | 21 | 8.62 (2.75) | 2.47 (1.75) | 5.09 (2.53) |
| S-hypermedia | 20 | 7.45 (1.96) | 1.20 ( .95) | 3.65 (2.25) |

Table 3 shows that students using the F-hypermedia identified more non-salient phenomena than students using the S-hypermedia ($F$(1, 39)= 8.20, $p$=.007 for structures, $F$(1, 39)= 6.19, $p$=.017 for behaviors, and $F$(1, 39)= 9.21, $p$=.004 for functions). However, there were no differences for the salient structures, behaviors or functions.

Table 3. Means and standard deviations of nonsalient SBF by hypermedia type.

| Group | N | Nonsalient | | |
|---|---|---|---|---|
| | | S | B | F |
| F-hypermedia | 21 | 3.29 (1.31) | .67 (.86) | 1.95 (1.40) |
| S-hypermedia | 20 | 2.15 (1.23) | .15 (.37) | .75 (1.12) |

## Discussion

Understanding the differences in conceptual representation between expert and novice is a critical starting point in developing the instructional materials because it points to the kinds of domain-specific thinking that are useful. The SBF conceptual representation captures the features of expert thinking about this domain, and thus may have the potential to facilitate student learning about the complex systems. Moreover, putting function first may also make the information more coherent. By stressing what the system does, how it accomplishes its function, and finally the structures involved, learners focus on deep understanding of the whole rather than superficial understanding of isolated parts. This study compared the effects of two different versions of hypermedia embodying alternative conceptual representations on student learning in a single domain. Overall the results of the SBF analyses demonstrated that the function-centered hypermedia helps students develop a deeper understanding of complex systems by moving their focus from superficial structural knowledge to the deep interrelated functions and behaviors as evidenced by their improved understanding of nonsalient structures, behaviors, and functions. We did not find any differences in the mental model analysis across conditions. However, Compared with the previous baseline study (Hmelo-Silver, Marathe, & Liu, 2004), the student mental models went from the egocentric level at baseline to a modal model at the simple healthy lung level. This result implies that even though students' mental model of the human respiratory system did not differ across conditions, the hypermedia intervention did help students understand the human respiratory system and that both versions of hypermedia helped students construct a more sophisticated mental model than the students in the expert-novice baseline study. It is also notable that in both conditions, students were more likely to mention behaviors than students in the expert-novice study. We suspect that even in the structure condition, there is more function and behavior information than in a standard text. This could be the reason for the improvement of mental model level compared with the previous baseline data.

In addition to the mental model analysis, the fine-grained SBF coding successfully captured the effects of alternative conceptual representations on complex systems learning. Students, rarely notice non-salient phenomena, because they are invisible and dynamic. The students in F-hypermedia condition better understood the nonsalient functional and behavioral aspects of the system than the S-hypermedia students as indicated by the improved student understanding of the system. This result might be contributed to the different conceptual representation underlying the F-hypermedia. The function-oriented conceptual representation highlights connections between salient and nonsalient phenomena. Thus students were able to see the link between the functions of nonsalient structures, the functions of the salient structures, and the function of the whole respiratory system, which was previously ignored by them. In contrast, without such a link, the structure-oriented hypermedia embodied the piecemeal conceptual representation, which failed to help students realize the importance of nonsalient phenomena. The results indicate that the SBF conceptual representation can be used as an instructional tool to help students organize and make connections among the huge amount of information (salient or nonsalient) in complex systems.

In order to replicate the results for other systems, and further investigate the effect of alternative conceptual representations we are currently developing additional hypermedia for learning about aquarium ecosystems. In addition, we are embedding the SBF representation in a curriculum that will be implemented in middle school classrooms in the coming year. Emerging theories of learning and thinking stresses the importance of integrating the roles of context, experience, and active engagement of learners (Wilensky & Resnick, 1999). Hence, in addition to the static hypermedia systems, we are developing computer simulations that help make behaviors and functions visible and more importantly provide opportunities for students to test and repair their ideas. We have developed simulations of gas movement and exchange in the alveoli and oxygen uptake at the cellular level. Students will be able to manipulate the variables and observe the difference these changes will make to the system at different levels and as a whole. This interaction with the complex causal system will also make the connections between different behaviors and functions explicit. For example, as students increase the need for energy, they will be able to see how this one change affects the oxygen demand, breathing rate, and heart rate. Moreover students will be able to see how these changes happen simultaneously and not just observe the end point differences. We feel that this dynamic interaction will help students better understand the nature of complex systems. It will also aid them in conceptualizing the system as function-driven. Overall the results of this study can inform future curriculum design in science education demonstrating that foregrounding function may be an effective approach to facilitating learning about complex systems.

## Conclusion

In considering the differences between expert and novice thinking, it is evident that conceptual representation matters. The SBF representation can be used in the hypermedia system to guide and support growth in student understanding about complex systems. Indeed, it can help student learning in two ways: 1) Making the functional perspective salient helps students see the interrelationships within a complex system; 2) The interrelated functions facilitate student to notice the existence of nonsalient elements that play extremely important role in the system.

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