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Promoting Transfer of Ecosystems Concepts

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ABSTRACT

This study examines to what extent students transferred their knowledge from a familiar aquatic ecosystem to an unfamiliar rainforest ecosystem after participating in a technology-rich inquiry curriculum. We coded students' drawings for components of important ecosystems concepts at pre and post test. Our analysis examined the extent to which each of the drawings showed evidence of understanding of photosynthesis, cellular respiration and decomposition. The results demonstrate that students experienced greater learning gains in aquatic systems (the learning measure) than in the rainforest (the transfer measure). However, they also made significant learning gains on the rainforest task from pre- to posttest, suggesting that students transferred some knowledge from one system to another. Further research is needed to examine a wider range of relevant concepts and more distant contexts.

KEYWORDS
Transfer, Ecosystem, Inquiry Learning

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Introduction

Ecosystem concepts provide a foundation for students to understand environmental issues. They are also crucial when students need to make sound decisions concerning the environment and society beyond school (Nicolaou, Korfiatis , Evagorou, & Constantinou, 2009; Maloney, 2007; Jordan,

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Singer, Vaughan, & Berkowitz, 2009; Mila & Santmarti, 1999). In particular, there are some big ideas, such as photosynthesis, respiration and decomposition that cut across many ecosystems, which are important for students to comprehend environmental issues (Ozay & Oztas, 2003). However, these concepts are difficult to learn, in part, because they involve complex and dynamic relations within systems (Eilam, 2012; Hmelo-Silver, Marathe & Liu, 2007; Hogan & Fisherkeller, 1996; Mohan, Chen & Anderson, 2009; Ozay & Oztas, 2003; Alparslan, Tekkaya, & Geban, 2003; Nicolaou, et al., 2009).

What makes understanding ecosystem concepts even more difficult is that some concepts may be presented in one context but not another. As a result, students are required to grasp structural elements as well as the relationships in one context and identify the corresponding structures and relationships in order to apply these to a new context. Mapping these correspondences may not be straightforward and thus poses challenges to students' analogical reasoning abilities. For example, students may learn about plant adaptation to wet conditions in tropical rainforests because of the popular appeal of rainforests. They are unlikely to make sense of plant adaptation to water in other environments, because tropical rainforests can pose unique constraints.

In this study, we examine whether an inquiry learning environment can promote students' transfer of ecosystem concepts. Specifically, we considered to what extent students transferred their understanding of photosynthesis, cellular respiration and decomposition from an aquatic ecosystem to a rainforest ecosystem. This study is part of a larger program of design research that seeks to understand how the Structure-Behavior-Function (SBF) conceptual representations can be used to design science learning environments that promote learning and transfer (Liu & Hmelo-Silver, 2009; Sinha et al., 2013). We explicitly portrayed a system's structures, functions, and behaviors in order for students to observe, model, and understand the relationships among form and function as well as the causal behaviors and mechanisms of complex systems. We define structure as components within a system, function as role or output of components in the system and behavior as causal mechanisms that enable system's function (Hmelo-Silver, et al, 2007).

Transfer

Transfer is defined as knowledge learned in one context can be applied to other contexts (Barnett & Ceci, 2002). It occurs if two situations (i.e. the base situation and the target situation) are analogous, meaning that they share common patterns of relationships between elements in the situation, problem, or context (Holyoak, 1995).The base situation is the context in which some knowledge or skill is initially learned whereas the target is the novel context to which knowledge or skills will be applied. For transfer to occur, individuals need to align relationships that connect elements in both the base and target situation (Reed, 2012). However, this is hard to achieve even when the situations are closely related—what is termed near transfer (Barnett & Ceci, 2002). This is particularly relevant in environmental education. For example, in a study of third graders learning about habitats, students who learned through large classroom-based instruction, which included activities of lecturing and watching videos, did not demonstrate transfer to a different context (Basile, 2000; see below). This is because environmental knowledge, which involves complex interactions between components from different levels, is difficult for students, not to mention to transfer the knowledge from one context to another (Schönborn & Bögeholz, 2009). Moreover, students' everyday experiences of environmental concepts conflict with scientific understandings (Alparslan et al., 2003). Therefore, environmental educators need to guide learners to see the relevance of what they are learning while taking into account prior knowledge (Milà, & Sanmartí, 2003).

Students' Conceptions of Ecosystems

Students bring naive ecosystem concepts into classrooms even before their formal education. For example, although photosynthesis involves sun, gas, and water, students may describe photosynthesis as "providing food for plants" which may conflict with their understanding of food as liquid and solid substances (Ozay & Oztas, 2003). Similarly, Eisen and Stavy (1993) found that students were confused by how plants make organic substances from chlorophyll and how the sun could be an energy source. Along the same lines, most of students' ideas about respiration come from common language as students use the terms respiration and breathing interchangeably to mean cellular respiration (Sanders & Cramer, 1992). Because of student's ideas that breathing occurs in the lungs, it can be challenging to understand how breathing might occur in plants, because they do not have lungs. Students also may not understand that substances other than air are involved. Alparslan et al. (2003) claimed that most students believe plants only photosynthesize during the day and that plants only respire at night when photosynthesis stops, which suggests that students have difficulty making connections between photosynthesis and respiration.

Related to these processes is the equally difficult concept of decomposition. In a study of student understanding of decomposition, Leach et al. (1996) found that students readily integrated knowledge of microbes as decomposers into their explanations of ecosystems. Hogan & Fisherkeller (1998) attributed this pattern to decomposition being more compatible with students' intuitive notion of food than photosynthesis. However, students still may have difficulties connecting decomposition with photosynthesis and respiration by oxygen or grasping the idea that decomposition consumes oxygen.

Ecosystems Learning

Environmental education researchers have approached the issue of designing curricula, with goals of promoting deep learning, as well as transfer. Basile (2000) contrasted two curriculum designs. One was characterized by traditional classroom teaching with activities that included lectures and watching videos. Another one was featured by inquiry practices with students playing roles of scientists who analyzed the data collected by them. Both curricula showed similar effects on learning, but only students in the inquiry curriculum demonstrated transfer. Warburton (2003) provided another example of curriculum design that aimed to foster deep learning in environmental education classrooms. Students were asked to engage in class discussions, constructing concept maps, and making connections with prior knowledge. These studies do suggest the importance of having contexts for students to apply (Mila & Starnicki, 2003). They also indicate an inquiry-based learning environment promotes students' deep learning and transfer. However, none of these studies focused on how conceptual representations can help learners construct coherent understanding of ecosystems concepts. Using hypermedia, Liu and Hmelo-Silver (2009) demonstrated that different conceptual representations could lead to different effects on learning and demonstrated that instruction organized around functional aspects of a human body system promoted deeper learning than instruction organized around structural aspects of a system. In this study, we will explore effects of a technology-rich learning environment that foregrounds a conceptual representation on students' transfer.

Here, we first oriented students with an overarching problem at the beginning of the curriculum about why there was a sudden fish kill in a local pond. Presented via a video, this provided students with a relevant context to anchor their learning. In order to solve this problem, students need to explore the mechanism of photosynthesis, respiration, and decomposition. Their explorations were embedded in a technology-rich curriculum (Hmelo-Silver, Eberbach, & Jordan, 2014). We integrated our visions of how the SBF conceptual representation, supports learning and transfer of ecosystem concepts in a technology-rich learning environment. Specially, we highlighted the functional aspects of the system by providing students with a hypermedia organized around functional questions, which emphasized mechanisms of the ecosystem (Liu & Hmelo-Silver, 2009). The hypermedia was a set of hyperlinked texts and graphics that presented information about ecosystems to students. It always started with questions about function at the top level and asked students to explore questions about mechanisms, and finally down to structures. This made the functional aspects of the ecosystems salient to students. We made behavior salient through the use of simulations that allowed learners to see the dynamic processes in action. We expected that foregrounding function and emphasizing the interdependence between structures, mechanisms, and functional levels of a system would promote students' deep understanding.

Methods

Participants and Classroom Context

Participants in this study included 57 seventh grade students, who were 13 years old, from two suburban public middle schools in the northeastern United States. Students learned about aquatic ecosystems over a period of four to six weeks.

The curriculum was developed in collaboration with the two classroom teachers and was revised between the first and second teacher's classroom enactments. Students learned about ponds and aquarium systems. However, these two units were presented in slightly different sequences. In classroom 1, the students were initially presented with a problem about fish dying in a local pond and then learned about aquariums as model to aquatic ecosystems. In classroom 2, the students first designed their aquarium and then were presented with the problem about fish dying. Within each unit, students engaged in inquiry through evaluation of various forms of scientific evidence that could explain why the fish died in the pond. After students finished processing the data gathered from the pond (e.g., temperature, chlorophyll, necropsy data, dissolved oxygen and the nitrate levels), they concluded that the dissolved oxygen level in the pond is low, which might have caused the fish to die; they also found the nitrate was unusually high. Students used two NetLogo simulations (Wilensky & Reisman, 2006). These macro level and micro level simulations involved carbon cycling and cellular respiration and allowed students to investigate the problem of why dissolved oxygen might have been low in the pond. The macro level simulation demonstrated the relationship between algae growth, sunlight and nutrient runoff in the pond. Students could explore the relationship between algae population and oxygen levels. The micro level simulation allowed exploring how bacteria mediate the relationship between oxygen level and algae population. Students still needed to determine why the algae bloom occurred and why the pond nitrate levels rose so high. Students then were introduced to eutrophication. Because of watershed and human impact (e.g., untreated sewage, etc.), nitrate and other nutrients were washed in to the pond caused the algae to bloom. This may also have explained why nitrate levels were so high in the pond. When algae blooms and dies, the bacteria decompose the algae depleting the oxygen, resulting in less oxygen being available for the fish. Students also created SBF models with the Ecosystem modeling toolkit to help them integrate and synthesize their ideas (Vattam, Goel, Rugaber, Hmelo-Silver, Jordan, & Gray, 2011). In addition, students used the SBF hypermedia for background information.

Data Sources

All 57 students completed pre- and posttests in which they were asked to complete a drawing of an aquatic ecosystem and indicate relationships within the system. Students were then asked to complete the same task but in a rainforest ecosystem that was not part of instruction. This second task served as the transfer task. The pre-test allowed us to examine students' baseline performance and to identify pre-existing understanding between the two ecosystems.

Coding

To examine the extent to which students were able to transfer what they learned in an aquatic system to a rainforest system, we coded their drawings in each of two ecosystems. We examined the extent to which students could provide evidence of understanding photosynthesis, respiration and decomposition in the base system (aquatic ecosystem) and the transfer system (rainforest ecosystem). To accomplish this, we developed three coding schemes based on expert understanding of photosynthesis, cellular respiration and decomposition. The three system concepts all include four learning and transfer levels ranging from zero to three (Table 1). One researcher performed the majority of the coding and a second coder coded 20% of the tests. Inter-rater agreement reached 99% for photosynthesis, 97.5% for respiration and 98% for decomposition.

Photosynthesis is a chemical process that converts carbon dioxide into organic compounds by using energy from the sun and releasing oxygen (Campbell, Mitchell, & Reece, 1997). Thus, we divided photosynthesis into four components:

Photosynthesis is a process

Gas is exchanged—plants absorb CO2 and plants release O2

Plants use energy from sunlight

Organic compounds are produced.

Initially, we coded each student's pre- and posttests for presence or absence of each component. For example, if students mentioned the growth of trees, plants make their own food, sunlight or energy from sun and plant growth and connecting them together, we would code the presence of this component. We coded this liberally because as long as students mentioned the sun and plant growth, it indicated that students were beginning to think about the effect of energy on plant growth. Figure 1, is an example of one student's inclusion of sun and plants in which the student annotated, "sun gives light and food source for plants." In this case, we coded for the presence of components: plants use energy from sunlight and organic compounds are produced. We also coded the presence of gas exchange because the student annotated "trees give out O2 and take in CO2." Thus, this student's final score is 3 as he or she mentioned three components and made connections between them. Similarly, in Figure 2 in the rainforest ecosystem, the student also received a final score of 3 as the student included these same components.

Respiration is a set of the metabolic processes using oxygen that takes place in the cell of organisms to convert biochemical energy from nutrients into ATP and releasing waste product— CO2 (Campbell et.al., 1997). Accordingly, we divided cellular respiration into four components:

Respiration is a process

Respiration is essential for all living things

As part of respiration, energy is released

Plants/animals breathe in O2 and release CO2.

We coded and scored each student's pre- and posttests for presence or absence of each component. We coded indications that refer to the fact that respiration is a dynamic process—dynamic could be coded if student mentioned that an animal eats for nutrients or for energy. We coded this liberally because as long as students mentioned food and energy, it indicated students were beginning to think the role of food in respiration—the first step towards thinking of cellular respiration. Students received credit if they indicated fish or animals need oxygen for survival or if they articulated the relationship between levels of O2 and fish survival (e.g., low oxygen level kills fish).

Decomposition is the metabolic process that breaks down materials into simpler components by living organisms. This process requires oxygen and releases nutrients (Campbell, et al., 1997). Consequently, we divided decomposition into four components:

Bacteria are essential to the ecosystem

Bacteria decompose using oxygen

The process of decomposition releases nutrients such as nitrate

Bacteria break down material.

We coded students' pre and posttests for presence and absence of each component. We also coded bacteria are essential to the ecosystem liberally. We coded it as present if students mentioned the beneficial role that bacteria plays in an ecosystem.

Results

Descriptive statistics are shown in Table 2. Because there were no main effects for teacher or significant interactions (all p's >.1) we combined data across the two teachers for all the analyses. To examine the overall effects, we ran a 2×2×3 ANOVA with contexts (aquatic ecosystem and rainforest ecosystem), time (pre-test and posttest), and processes (photosynthesis, respiration, and decomposition) as within-subject factors. The results suggested significant interactions between context, process, and time, $F(2,112) = 9.28$, $p < .001$. To better understand this three-way interaction, we conducted simple effects tests and computed effect sizes. These tests showed that students demonstrated significant gains over time in both systems. For photosynthesis, there were significant gains for the aquatic system ($t(56) = 7.49$, $p < .001$, $d = 1.41$) and for the rainforest system ($t(56) = 3.85$, $p <.001$, $d =.63$). For respiration there were significant gains for both the aquatic system and rainforest system ($t(56) = 10.88$, $p < .001$, $d = 1.61$ and $t(56) = 3.43$, $p < .001$, $d = .66$ respectively). Similarly, there were gains for decomposition from pre to post on the aquatic and rainforest system ($t(56) = 10.09$, $p <.001$, $d = 1.65$ and $t(56) = 2.20$, $p < .03$, $d = 0.40$ respectively).

Students showed little evidence of understanding these concepts at pre-test and showed significant gains for both systems at posttest. The gains for the aquatic system are an indication of learning. The gains for the rainforest system, which was not a focus of instruction, were also significant, though with smaller effect size, indicating that there was some transfer to another ecosystem system context.

In addition to these quantitative results, Figures 1 and 2 show examples of posttest drawings for one student. At posttest, this student had a score of 3 on the aquatic system and 3 on the rainforest system for the concept of photosynthesis. Our analysis suggests that this is an example of transfer as some of the ideas that the student demonstrated in the source system (aquarium) were also observed on the transfer system (the rainforest). Mappings across the two systems of this student are shown in Table 3. The student demonstrated use of three of the four photosynthesis components in both drawings. Although the aquatic drawing is more elaborated than the rainforest drawing, the drawings indicate that this student considered cellular respiration and decomposition processes as well as the role of bacteria at a high level (i.e., bacteria decompose waste and dead matter) in both systems. Likewise, this student showed other consistencies related to digestion (“eating”) and reproduction in both aquatic and rainforest ecosystems. Nevertheless, this student did not take all functions into the transfer context as excretion and the need for space were only observed in the aquarium context. This suggests that this student, whether correctly or incorrectly, created these mappings selectively.

Discussion

The results from this study indicate students can transfer their knowledge from the aquatic ecosystem to the rainforest ecosystem, in contrast to much laboratory research and classroom studies, Learning environments need to be designed with transfer in mind or students may fail to transfer what they have learned (Basile, 2000; Perkins, 1993). Here, we found students were able to transfer the complex ecosystem concepts without being prompted or explicitly taught.

We attributed the significant pre-to post test change to the technology-rich curriculum in which students participated. Throughout the curriculum, we contextualized students’ learning with an over-arching question. Students used a hypermedia and two simulations to explore mechanisms and relationships among ecosystem concepts in order to solve the problem. The technological tools were constructed to embody the Structure-Behavior-Function conceptual representation, which aims to promote students’ understandings of complex mechanisms and relationships of ecosystem concepts (Hmelo-Silver et al., 2007).

The functional aspects of the conceptual representation and situating students’ learning within a real-world problem as part of our curriculum is well aligned with central features of curricula design in environmental education.

Environmentally literate individuals need to be competent in analyzing, investigating, and evaluating environmental issues using evidence, while being knowledgeable about environmental and ecological systems (NAAEE, 2011). Additionally, Ernst and Monroe (1996) suggest that environmental education should be centered on local places and issues. With emerging community-engaged science programs, local sustainability issues, such as eutrophication in local ponds featured in our curriculum, can serve as an effective platform to meet environmental and science education goals (Wals, Brody, Dillon, & Stevenson, 2014). Furthermore, modeling, also featured in our curriculum, can be an effective tool to encourage environmental issue learning (Crawford & Jordan, 2013). Taken together, our approach to designing our curriculum; i.e., anchoring ideas, using a unifying theme, and encouraging a logical progression, has been suggested as features of effective environmental education curricula (Warburton, 2003).

Despite the promising findings, we acknowledge the limitations of this study. The first is the pre-post test design. Although a comparison group would allow stronger causal inferences, the research literature suggests that students made progress on concepts that are normally resistant to instruction. In this study, we used drawings to examine learning and transfer. Growing recognition in the environmental education community is that any single strategy has limitations for tapping into the entire range of learning outcomes (Andrews, Tressler, & Mintzes, 2008). In drawings, we cannot distinguish whether students' exclusion of components and relationships from their drawings is because they did not understand the mechanism or they did not draw it. Future studies need to include multiple ways to trace students' understanding. Although the findings were statistically significant findings, their magnitude was small. The intervention oriented students' toward thinking about the overarching question of why fish died in the local pond. This may have bounded their understandings in the pond ecosystem and made the transfer to other systems more challenging (Salomon & Perkins, 1989). Future iterations should include a reflection component throughout the instructional unit to encourage learners to think about how the knowledge they learned in the context of aquatic systems might apply more broadly. Nonetheless, the use of conceptual representations shows promise for promoting learning and transfer of difficult ecosystems concepts.

Table 1

Learning and Transfer Levels

Level	Numbers of Components in Photosynthesis, respiration, Decomposition
0	No components
1	One single component
2	Two of the four components plus some connections or three of four components without showing any relationships among them
3	Three of four components and showed some evidence of relationships among them.

Note: The 0-3 scale represents a continuum from 0 indicating no evidence of understanding and a 3 indicating good evidence of understanding. All coding were conducted for both the aquarium system and the rainforest system. For photosynthesis and respiration, in order to reach 3 points , students need to mention both aspects of gas exchange.

Table 2: Means and standard deviation of scores (levels), by context and time of tests

Systems	Photosynthesis		Respiration		Decomposition	
	Pre	Post	Pre	Post	Pre	Post
Aquatic System	0.07 (0.32)	1.05 (0.93)	0.03 (0.16)	0.84 (0.68)	0 (0)	1.35 (1.16)
Rainforest System	0.04 (0.19)	0.40 (0.78)	0 (0)	0.23 (0.49)	0 (0)	0.16 (0.57)

Table 3: Mappings of components across systems

	Aquatic System	Rainforest
Energy	Sunlight gives light to organisms	Sun gives light
Gas exchange	Plants give out oxygen and take in CO2	Trees give out O2 and take in CO2
Organic compound	Food sources for plant	Food source for plant
Photosynthesis is a process	Not mentioned	Not mentioned

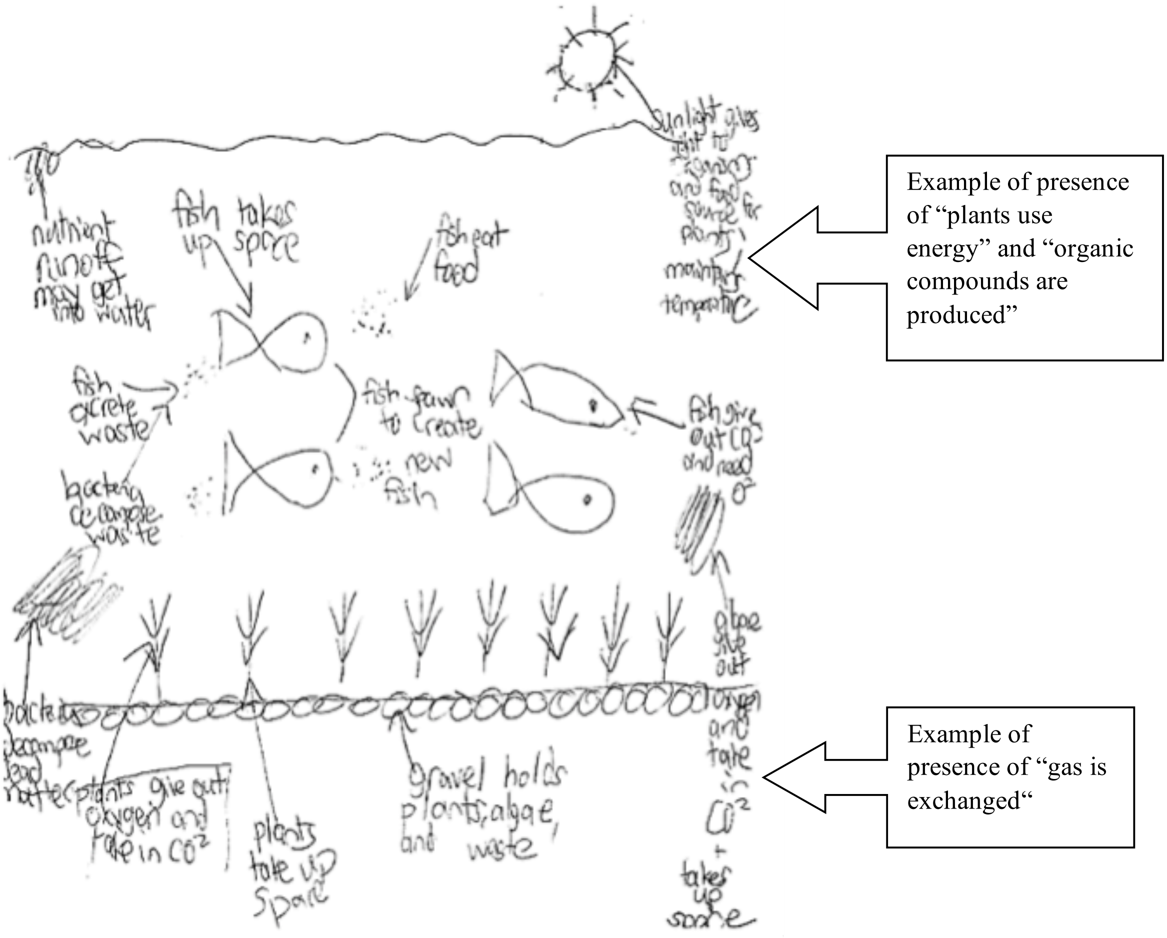

Figure 1. Example of student’s post-instruction drawing of aquatic system

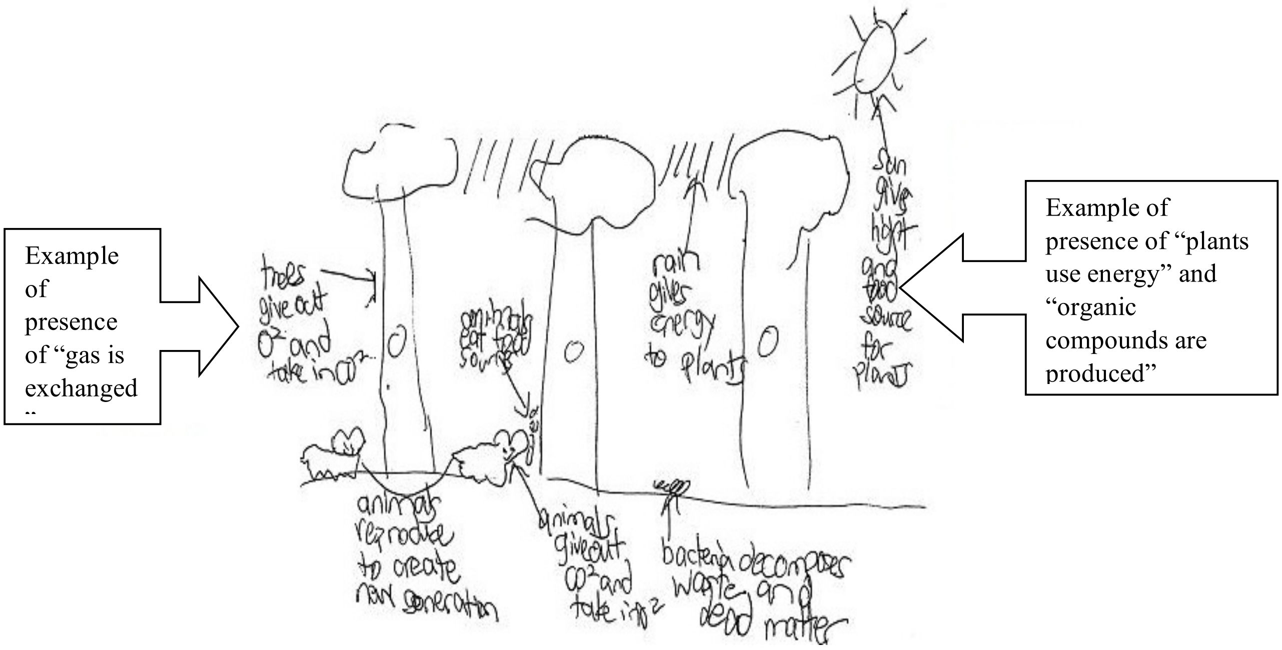

Figure 2. Example of student's post- instruction drawing of rainforest systemDisclosure statement

No potential conflict of interest was reported by the authors.

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Dr. Suparna Sinha is a PostDoctoral Associate at the Center for Math, Science and Computer Education. She is interested in understanding influences of technological affordances (of simulations, hypermedia and modeling tools) on collaborative engagement and subsequently how student's collaborative engagements in technology intensive learning environments influences individual transfer of learning.

Yawen Yu is now working as a curriculum developer and designer at Manpower Group China. Before joining Manpower group, Yawen's major research interests include how do technological tools support students' collaborative learning on complex concepts. Yawen received her Master's training from Rutgers University and Boston University.

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