Minshew, L. M., Barber-Lester, K. J., Derry, S. J., & Anderson, J. L. (2017). Leveraging Students' Knowledge to Adapt Science Curricula to Local Context. *Educational Technology & Society, 20* (4), 205–218.

Leveraging Students' Knowledge to Adapt Science Curricula to Local Context

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ABSTRACT

Conceptions of ecological processes such as the flow of energy and cycling of matter in an ecosystem are increasingly important understandings in a rapidly changing world. This study utilizes a p-prims, or knowledge in pieces, lens to examine understandings and disconnections in students' conceptualizations of energy flow and matter cycling specific to our context. Findings from our analysis drove continued refinement of our "Compost" curriculum through modifications designed to build on students' p-prims and foster deeper understanding of ecological processes.

Keywords

Design-based research, Knowledge in pieces, Prior knowledge, Ecological processes

Introduction

Now, more than ever, dilemmas such as pollution and climate change have made it imperative that students become knowledgeable about ecosystems. The Next Generation Science Standards (NGSS Lead State, 2013) align with these growing concerns, having included several ecology standards at the elementary and middle school levels.

In order to fully grasp ecological issues, students need knowledge of complex phenomena such as the cycling of matter and the flow of energy within ecosystems. Research indicates (e.g., Bell-Basca, Grotzer, Donis, & Shaw, 2000; Hogan & Fisherkeller, 1996; Honwad et al., 2010) that ecological concepts such as those require knowledge from both life and physical sciences. Hmelo-Silver and Azevedo (2006) acknowledge the cognitive challenges students face when engaging with complex systems such as ecosystems. Consideration of the vast knowledge required for expert-like understanding of ecosystems as complex systems suggests that student conceptual understanding will necessarily develop over time. Delving deeper into the intricacies of scientific understanding can be a challenge for students due to their limited experiences with these complex phenomena. Yet, as with all learning, student prior-knowledge is important for science understanding. Students' experiences in local ecosystems contribute to prior conceptions of ecological phenomena that they bring to the classroom.

An emerging approach from the Learning Sciences is diSessa's (1988, 1993; 2014) Knowledge in Pieces (KiP) framework, which frames student prior-knowledge from a resource-oriented perspective. The KiP framework posits that students have knowledge fragments or pieces of scientific understanding and that restructuring the fragments will aid in development of a deeper, more complete understanding of the scientific phenomena (diSessa, 1988). Student prior understanding is considered primitive, as it is generally an everyday understanding, as opposed to an expert scientific understanding. This perspective counters the historically prevalent misconceptions perspective (Hammer, 1996), which views student non-scientific understanding as incorrect and an obstacle to be overcome.

The KiP framework has been used to understand and analyze student thinking in the context of physics, but has yet to be applied to the study of ecology, specifically the cycling of matter and the flow of energy in an ecosystem. The goals of this study were to examine student conceptualization of these two ecological phenomena through a KiP lens and then determine how student understanding could be leveraged for design modifications to enhance deep learning. Our study examined data collected prior to and directly after the implementation of a curriculum called "Compost." Compost is a project-based, technology enhanced biology curriculum that focuses on the flow of energy, sustainability, and the cycling of matter in ecosystems. The research questions that guided this study were (1) What KiP related to flow of energy and cycling of matter in ecosystems do students bring with them to the classroom? (2) How can consideration of students' KiP inform curriculum design, modification and implementation to promote deep learning about energy and matter in ecosystems?

Literature review

Knowledge in pieces

Constructivism posits that students build their understanding of the world around them as they engage in activities both socially and alone. The constructivist approach suggests that learning occurs in phases and recognizes that expert understanding is built up gradually over time (Smith, diSessa, & Roschelle, 1994). From this perspective, student prior knowledge is valuable and initial learning phases are expected to include many incomplete and partial understandings. As existing knowledge is challenged and students are provided opportunities to refine and transform their knowledge, their understanding becomes more sophisticated (Smith et al., 1994). DiSessa developed the KiP framework with these characteristics of constructivism in mind. According to diSessa (2014), students have thousands of primitive ideas or understandings which he calls phenomenological primitives (p-prims). P-prims are loosely organized and highly contextual to student experience (diSessa, 2014).

KiP describes student incorporation of new concepts as a “reweaving” of knowledge (diSessa, 2014, p. 98). In other words, activated p-prims become interconnected with new information and transform student conceptual understanding; p-prims are not eliminated or eradicated. This is in contrast to misconceptions literature that suggests that learning is a process of replacing misconceptions with expert knowledge in a rapid fashion (Smith et al., 1994).

DiSessa and colleagues have done considerable work utilizing KiP in the realm of physics (e.g., diSessa 1988; diSessa, 1993; diSessa, 2014; Smith et al., 1994). These studies consider student intuitive ideas about physics and how those ideas influence formal school instruction of physics. The research recognizes that students interact with the physical world around them and that these experiences influence student understanding and explanation of the physical phenomena.

Knowledge in pieces in life and earth sciences

KiP has been used sparingly for the study of earth and ecological sciences. Two studies directly reference KiP and discuss its merits within the field of ecology. Parnafes (2012) applied KiP to students developing explanations about the earth science concept of the phases of the moon. Parnafes (2012) suggests that because KiP reduces the grain size of analysis concerning student understanding (i.e., p-prims), it highlights the information that needs to be reworked to construct a scientific explanation. Özkan, Tekkaya, and Genan (2004) found that KiP was more appropriate to use than misconceptions when discussing student conceptual understanding of ecological concepts.

Theoretical grounding

The current study is framed by constructivist assumptions that learners’ prior knowledge is an important facet of learning and that learners are active in developing knowledge for themselves (Smith et al., 1994). Constructivism emphasizes the role of prior knowledge in learning and accepts scientific inaccuracies as characteristic in students’ initial phases of learning (Smith et al., 1994). DiSessa’s KiP provides a framework upon which to discuss student conceptual understanding of ecological processes and gradual construction of scientific understanding. It utilizes the constructivist tenet of valuing student prior knowledge and emphasizes the gradual development of student conceptual understanding of complex topics such as ecological processes.

Methods

Research design

This study is a part of a larger National Science Foundation (NSF) supported Design-Based Research (DBR) project called Biosphere. The project aims to develop a middle grades science unit called Compost. Compost is a collaborative, technology-supported, inquiry Biology curricular unit focused on energy and sustainability issues that is suitable for under-resourced middle schools in rural areas of the United States. DBR is characterized by iterative cycles of data collection, analysis, and reflection to inform the design of educational innovations and advancement of educational theory (Easterday, Lewis, & Gerber, 2014).

An important element of DBR is the nature of partnership between researchers and practitioners that drives the design and implementation of the work in authentic context. For this project, the cooperating teacher contributed to the initial design of the curriculum, and has had ongoing involvement throughout development and testing.

DBR as a research approach offers flexibility of implementation and design to fully understand the context in which a study is conducted. Easterday and colleagues' (2014) model (Figure 1) has six distinct and iterative phases: Focus, Understand, Define, Conceive, Build, and Test. Each phase produces important research and is used iteratively to refine and advance both iteration and theory. Our study reports on the Test phase in which researchers, along with a participating classroom teacher, implement and learn about the developed innovation Compost. The data collected during this Test phase was analyzed to refine the design problem and to gain an understanding of student conceptual understanding concerning the cycling of matter and the flow of energy in an ecosystem.

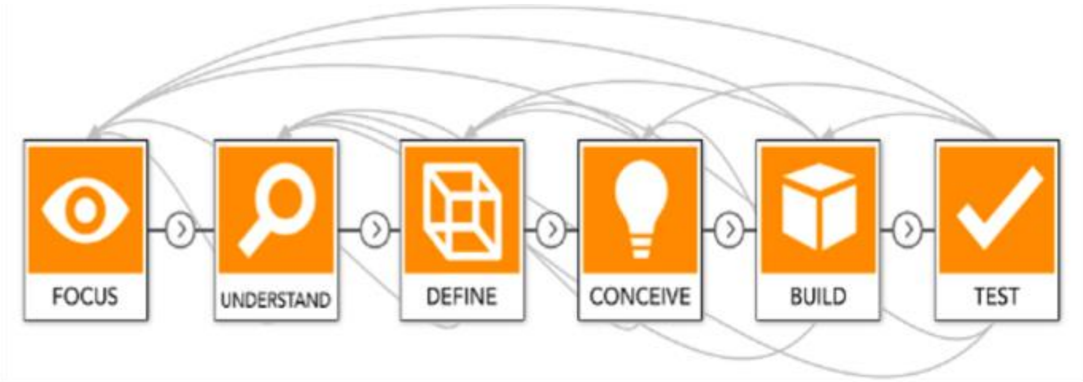

Figure 1. Steps in design-based research (Easterday, Lewis, & Berber, 2014)

Participants

All participants in the overarching DBR project were in the sixth grade (*n* = 94) at a small rural science, technology, and engineering focused, one-to-one technology, middle school in the southeastern portion of the United States. Students were from demographically diverse backgrounds: 31% white, 47% African American, 18% Latino/a, 3% Bi-racial, and 1% Asian. The school was identified as a Title I school, indicating that over 40% of the student population qualified for free or reduced lunch. The students all had the same sixth grade science teacher. Of those 94 students participating in the overarching DBR project, 12 focal students were selected by the teacher for deeper study. These 12 students were purposefully selected to reflect diversity of the student population both academically and demographically.

Compost curriculum

The Compost curriculum is an 8-week long, project-based, technology-enhanced inquiry science curriculum. Students build, collect data on, and modify a compost bioreactor in order to develop compost that decomposes quickly. Students utilize computer simulations to run tests on virtual compost piles and collect secondary inquiry information via an online reference tool. The curriculum also consists of several hands-on activities that provide students with experiences surrounding ecosystems, the cycling of matter, and the flow of energy.

Data sources

Model-based assessment

Consistent with our constructivist theoretical framework, we elected to utilize an open ended, Model-Based Assessment (MBA). Using the MBA is consistent with previous research that utilizes model building to demonstrate student conceptual understanding concerning the flow of energy and the cycling of matter in ecosystems (e.g., Hogan, 2000; Lin & Hu, 2003). These studies were able to effectively capture patterns and trends expressed at pre- and post-time points by having students construct models to demonstrate their knowledge concerning the cycling of matter and the flow of energy in ecosystems. The MBA is one way to capture student understanding of complex systems. Complex systems, such as ecosystems, have multiple levels of organization (Hmelo-Silver & Azevedo, 2006) and it can be difficult to capture student understanding of this kind via a standard assessment.

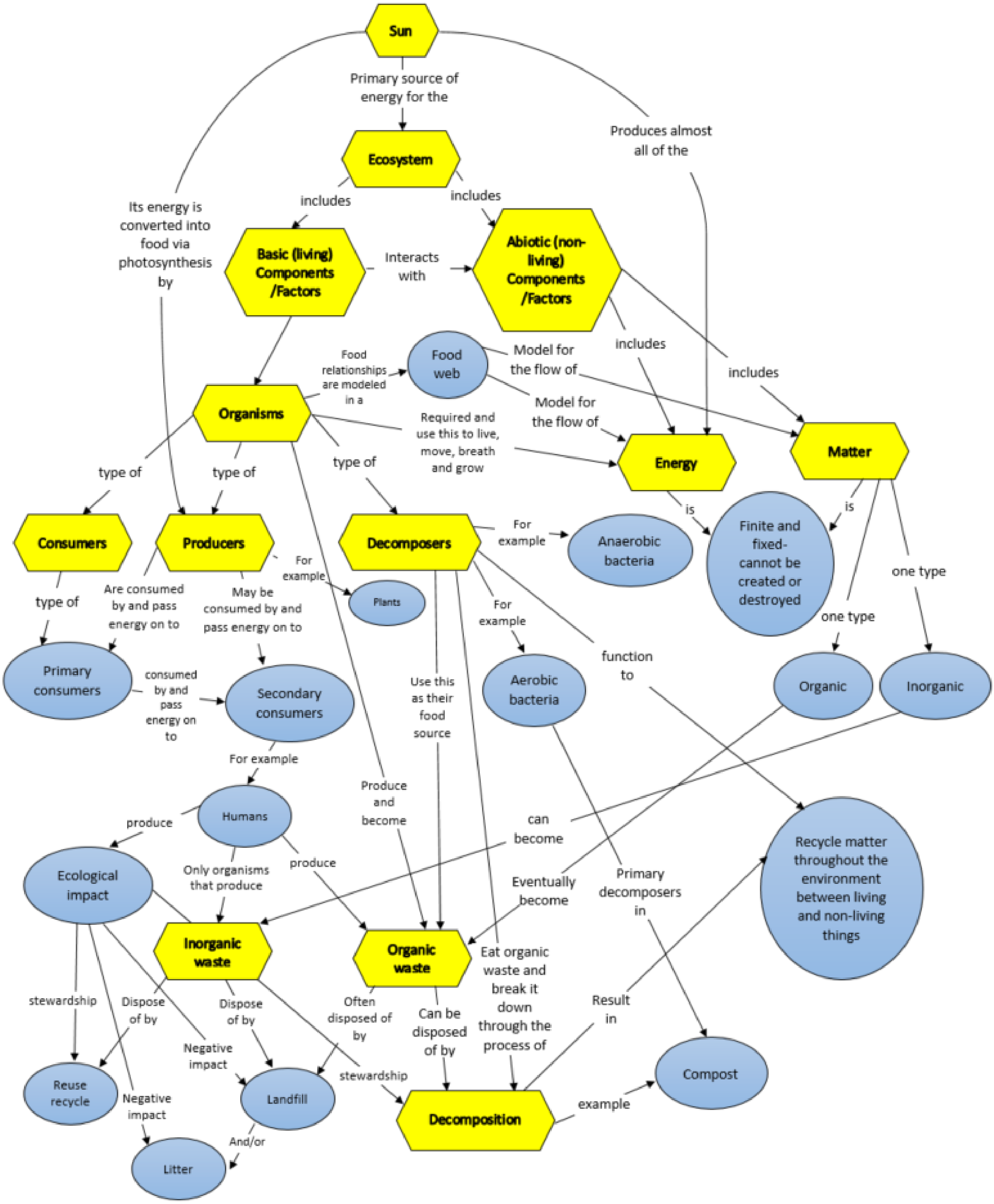

Figure 2. Consensus model

During the development of the Compost curriculum, the research team created a consensus model of concepts and relationships relevant to energy and matter that were central to the unit (See Figure 2). The consensus model was developed in a three phase process. First, the research team, including two science experts, developed a list of concepts central to the topic areas of flow of energy and cycling of matter that would be expected to fall within the scope of the curricular unit. From there a member of the team drafted the model, which was then presented to the team for review and feedback. In the final step, changes were made to the model based on team feedback. The consensus model was then used to develop the MBA by focusing on creating an assessment that would elicit evidence of student understanding of key concepts and relationships relevant to energy and matter.

The MBA was open and flexible, allowing students to show their understanding in ways reflective of their own knowledge construction. The MBA provides information about deeper understanding by requiring students to apply and represent their own understandings of key concepts without the use of pointed prompts or questions. Figure 3 is a sample of one student's MBA.

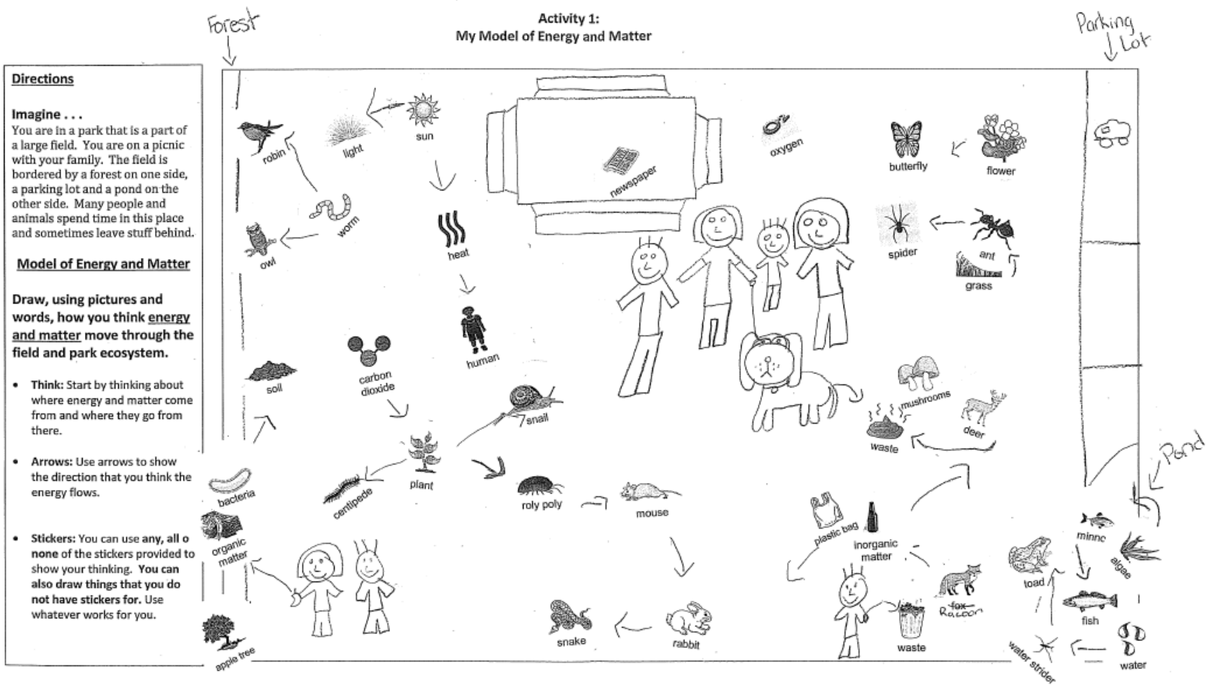

Figure 3. Student example of model based assessment

The MBA was administered by the cooperating teacher during students' regular science instructional time, and was completed prior to and after the implementation of the Compost curriculum. In addition to being read aloud, the instructions and scenario were on the paper provided. Students were supplied space to generate their model along with a set of stickers, which included elements and organisms common to the scenario ecosystem. Students could use their own drawings and the stickers to depict their model of how energy and matter moved and cycled within the ecosystem.

Interviews

The 12 focal students were interviewed about their MBA within one week of students completing their MBA prior to and after the implementation of the Compost unit. Interviews were conducted to capture student thinking about energy and matter in ecosystems beyond what could be interpreted from examining the MBA in isolation. Students were prompted to explain their MBA to the interviewer. Upon completion of their explanation, students were then probed about specific components (i.e., What do the arrows represent? Can you explain to me about the energy in this model?). Interviews were video recorded to capture the full extent of the interview (i.e., student comments and gestures).

Analysis

The pre- and post-interviews of 11 students were transcribed and analyzed, totaling 22 interviews in all. The 12th student was unavailable for a post-interview due to numerous school absences. That student's pre-interview was, therefore, dropped from the analysis due to incomplete data. The data were analyzed through interaction analysis, coding and stepwise reduction through data display and summary analysis.

Interaction analysis

The initial phase of analysis included Interaction Analysis (IA; Jordan & Henderson, 1995) for three of the student interviews. Interaction analysis is an in depth process that involves repeated viewing and noting of video selections by a team of researchers. Audio-recordings of the IA sessions and session notes were analyzed to identify salient themes within the students' interviews. Five major themes emerged from the analysis of the IA sessions: energy, matter, food chains, decomposers, and waste.

Coding

In the second phase of analysis the entire corpus of twenty-two interviews was coded for student p-prims using the themes identified in the IA sessions as initial broad start-codes. Interview segments were coded with the unit of analysis for each code typically being the talk-turn, but sometimes being a portion of a talk turn when multiple concepts were discussed within a single talk-turn. For the first step of the coding process, two members of the research team coded a single interview. Following the independent coding, the researchers cross-checked their application of the start codes. The cross-check process confirmed that both researchers applied the codes consistently, with no disagreements. A single researcher coded the remaining twenty-one interviews. Table 1 depicts the five major topic areas and the associated p-prims along with student quotes to illustrate the p-prims.

Table 1. Topic areas and p-prims

Topic area	P-prims	Student quote from pre-interview	Student quote from post-interview
Food chains	There is a relationship between sun/sunlight and producers	"Okay, so I connected the plants to the light, because the plant is a producer." (Mireya)	"I put the producers and sun and water together because that is what the producers need to grow." (Mireya)
	Animals eat other animals.	"I made a food chain to show how other things eat off other things to get food and energy. So I made a plant, then a rabbit eats the plant, then a snake eats a rabbit, then a fox eats the snake." (Jaylen)	"Well the energy flows from the grass to the rabbit, from the rabbit to the snake, from the snake to the owl." (Olivia)
	Animals eat plants.	"The deer needs the producers so they can eat." (Francisco)	"Producers make food for themselves and other living things." (Jaylen)
	Decomposers are a part of the food chain.	"Then the fox eats the snake, and humans eat other animals, but bacteria breaks down other foods and things so that's why I put that at the top." (Jaylen)	"It starts from the producer, then it goes to the consumer, then decomposers. The producers make the food and then the consumers eat the producers then the decomposers eat the consumers and the plants." (Mireya)
Decomposers	Bacteria, worms and mushrooms are decomposers.	"The mushroom is a decomposer, the worm is a decomposer too." (Malcolm)	"So like when you have waste and they [mushrooms] can decompose it. Then it goes back into the soil and gives the soil all rich nutrients" (Malcolm)
	Decomposers break things down.	"Mushrooms and bacteria um break down waste" (Francisco)	"You will need the worm to break down the waste and turn it into soil and the soil can be used to create plants." (Tori)
	Decomposition is connected to compost.	N/A	"So I tried my best to draw a compost pile. I drew included all like the greens and the browns 1, 2, 3. Then I drew several decomposers around it." (Cierra)

Waste	Animals and humans generate waste.	“The deer would leave the waste and like the waste would help the soil.” (Olivia)	“Waste I would describe like animals like they poop and then like for us humans we have certain wastes like stuff that we don’t eat, banana peels, apples cores. They’re all really not gonna be of use any more.” (Malcolm)
	Some waste can be broken down and is connected to soil.	“Bacteria break down waste so that plants can use it.” (Francisco)	“The waste when it breaks down, nutrients grow down there [points to the soil depicted in his model] and they help the grass grow.” (Ethan)
Energy	The sun is central to energy.	“It is basically all about the sun, the energy and how it spreads out for the whole forest.” (Leandra)	“The sun, the light, and the heat that gave off energy to like start up the producers.” (Olivia)
	Rain and clouds are connected to energy.	“Rain is the energy for the plant because it makes the plants grow.” (Jaylen)	“Sun and water drops help plants grow, and oxygen and carbon dioxide in the air also helps.” (Jaylen)
	Organisms need energy.	“The sun umm helps us get energy and it goes to the plants.” (Fatima)	“I thought maybe that [decomposers] would need energy in order to break down what they needed to break down.” (Tori)
	Electricity is connected to energy.	“So I did that to show that the energy, the battery connected to the light pole will be energy because the battery helps the light come on.” (Devon)	“Okay, first I drew the solar panels, the sun helps the solar panels and gives energy to the solar panel, the solar panel gives energy to light.” (Devon)
Matter	Everything is matter	“I mean all of it is matter because everything is made up of matter, but then I don’t know.” (Olivia)	“Matter makes up everything so matter is everywhere.” (Olivia)
	Matter exists in different states.	“Liquid ... [points to water sticker] solid [points to the human sticker] ... gas [points to oxygen sticker].”	N/A

Results

In response to our first research question, our analysis demonstrated that KiP is a useful and applicable framework for understanding and analyzing student knowledge related to ecosystems. Analysis of the interviews revealed six main areas in which students held various p-prims. The following sections present student p-prims within each topic area from both pre- and post-interviews highlighting shifts in these p-prims evidenced in the student interviews.

Food chains

The topic of Food Chains was prevalent within student interviews; eight of the eleven students spoke at length about the topic at both time points. Student explanations related to food chains included both implicit and explicit references. A few students explicitly used the term “food chain,” while others included descriptions of elements of food chains (e.g., producer-consumer relationships) without explicitly naming their depiction as a food chain. Changes from pre- to post-interviews centered on student ability to provide details about food chains and the frequency with which they spoke about food chains. The following are p-prims related to food chains found during analysis.

There is a relationship between sun/sunlight and producers

Six students connected the sun or sunlight to plants or producers during their pre-interviews. The nature of the relationship described between the sun and producers varied among students. Some students simply connected the sun to plants without specifying the nature of the relationship, while others articulated the connection between the sun and plants in terms of the energy that the sun provides to plants. For example, Mireya stated, “Okay, so I connected the plants to the light, because the plant is a producer.” However, not all students expressed this p-prim in their pre-interviews. In contrast, during their post-interviews students’ connection between the sun and plants was slightly stronger with eight of the eleven students making the connection. In her post-interview Mireya said, “I put the producers and sun and water together because that is what the producers need to grow.” She was able to provide a few more details about why the producers and the sun should go together. Other students held p-prims that connected the sun to plants in their post-interviews whereas they had not made this connection in their pre-interviews.

Animals eat other animals

In their pre-interview explanations, eight students put a major emphasis on the chain of consumption of smaller animals by larger animals. Common examples included birds eating worms and snakes eating rabbits. The idea of consumption was connected by two students to animals’ need to consume other animals to obtain energy. Jaylen noted, “I made a food chain to show how other things eat off other things to get food and energy. So I made a plant, then a rabbit eats the plant, then a snake eats a rabbit, then a fox eats the snake.” Jaylen indicated that the food chain not only showed animals consuming other organisms for food but that this was how energy was obtained. Whereas Mireya stated, “I connected the owl and the snake together because I tried to make it look like a food chain,” demonstrating that this student had a p-prim for animals eat other animals but it was not as developed as Jaylen’s p-prims. Animals eating other animals continued to be a prevalent idea expressed in student post-interviews. Olivia was able to articulate, “Well the energy flows from the grass to the rabbit, from the rabbit to the snake, from the snake to the owl” demonstrating that she knew that when animals consumed other organisms they obtained energy which she did not discuss during her pre-interview.

Animals eat plants

Similarly, the same eight students provided examples of animals eating plants. The most common example included was rabbits eating grass or plants. The consumption of plants by animals was connected by several students to the animals’ need for energy, which the plants provided. Several students used the words “producers” and “consumers” to describe the relationship between plants and animals. Francisco demonstrated this p-prim when he said, “the deer needs the producers so they can eat.” This p-prim remained relatively constant from pre- to post-time points, with one addition being that students articulated that plants produced their own energy and provided the energy for consumers during their post-interviews. For example, Jaylen noted in his post-interview, “producers make food for themselves and other living things.”

Decomposers are a part of food chains

Jaylen was the only student to connect decomposers to food chains during the pre-interview. However, five students were able to connect decomposers to food chains during their post-interview. Mireya, for example, stated in her post-interview, “The producers make the food and then the consumers eat the producers then the decomposers eat the consumers and the plants.” Mireya was able to connect producers, consumers, and decomposers, together to construct her conception of a food chain, which in her pre-interview only consisted of stating, “an owl and a snake are connected.”

Decomposers

Decomposers and the process of decomposition is central to the Compost curriculum. When the curriculum was developed it was anticipated that students would have nominal understanding about decomposers and decomposition. The interview and analysis process revealed that eight of the eleven students acknowledged decomposers in their MBA pre-interview and all eleven students discussed decomposers in their post-interview. The following is a discussion of the p-prims associated with decomposers and decomposition.

Bacteria, worms, and mushrooms are decomposers

At the time of the pre-interview three students had p-prims that allowed them to correctly identify bacteria, worms, and mushrooms as decomposers. Other students named bacteria, worms, and mushrooms as being a part of the ecosystem depicted in their MBA's but did not identify these organisms as decomposers. For example, Fatima commented, "bacteria is mostly kind of everywhere on the ground." Fatima has a p-prim that puts bacteria into the environment but she does not articulate bacteria's role within the environment. In their post-interviews nine students directly identified bacteria, worms, and mushrooms as decomposers while the remaining two students used the general term decomposer. Tori did not talk about decomposers at all in her pre-interview nor did she have them depicted in her pre-MBA. In her post-interview, however, Tori specifically included and identified bacteria, worms and centipedes as decomposers.

Decomposers break things down

Five students had p-prims at the pre-interview associated with the idea that decomposers break things down. Their expressed understanding ranged from stating simply that decomposers break things down to explaining that bacteria break down waste and put organic matter back into the soil. Francisco expressed, "mushrooms and bacteria um break down waste." Francisco does not identify the organisms as decomposers but has the p-prim that the organisms serve the purpose of breaking down waste. In contrast, Cierra demonstrated stronger organization of p-prims articulating that, "the bacteria and mushrooms … they break down, if an animal dies or something like that it will decompose the dead body into like organic matter that the soil to use and then it makes the ecosystem even healthier." Nine students had the p-prim that decomposers break things down at the post-interview. With the majority of students indicating that the broken down material is put back into the soil to improve the environment.

Decomposition is connected to compost

Three students introduced a third p-prim, connecting decomposition and compost, in their post interviews. Jaylen identified waste, organic matter, greens, and bacteria as elements within compost. Cierra drew a compost pile in her MBA with several decomposers surrounding it. Tori referenced the connection between decomposition and the compost bottles that students created and studied during the Compost curriculum.

Waste

The majority of the students interviewed incorporated waste into their models and explanations in some form in both their pre- and post-MBAs, yet how they discussed the concept of waste differed. Of the students that included waste in their explanations, incorporation ranged from only including a mention of trash to a fleshed out comparison between organic and inorganic waste. Two p-prims related to waste were identified.

Animals and humans generate waste

Waste generated by humans was most frequently connected to the idea of "trash." Students used the word "trash" specifically on multiple occasions, and provided examples of things that were human generated waste, such as a plastic bag. Students connected animal waste to the idea of feces. One of the stickers provided for students to choose from was a picture of feces labeled "waste." Students frequently connected animals to this sticker, and used the word "waste" to describe the sticker. This p-prim was salient and changed little from pre- to post-interviews with eight students discussing the p-prim at both time points.

Some waste can be broken down and is connected to soil

Three students in their pre-interviews connected animal waste with decomposition. As demonstrated earlier, students noted that decomposers break down animal waste. Francisco articulated that, “bacteria break down waste so that plants can use it,” while Olivia noted that animal waste “would help the soil.” The process of decomposition tended to be connected to animal waste and not to human waste. One student, Cierra, exhibited a much more advanced explanation during her pre-interview, differentiating between “organic matter” and “inorganic matter.” Cierra explained, “organic is the stuff being able to be decomposed” and inorganic as potentially harmful to the environment, “because the decomposers cannot decompose it.” The number of students expressing the p-prim that waste can be broken down and is connected to the soil increased from pre- to post, with eight of the eleven students articulating the connection. Cierra maintained her p-prim for the difference between inorganic and organic matter while other students demonstrated primitive conceptions of inorganic and organic waste. For example, Mireya stated, “We produce this waste [points to the sticker displaying feces] and this is like when people just throw trash out [points to the sticker depicting a trash can].” Mireya did not use the terms organic and inorganic when describing the scenario, but her statement does indicate that she recognizes that there is a difference between the two types of waste.

Energy

The flow of energy in an ecosystem is a complex topic. Food chains, as mentioned above, are salient in students’ understanding of how energy is passed from organism to organism in an ecosystem. In addition to the p-prims related to food chains, evidence for four distinct p-prims related to energy was present in student interviews.

The sun is central to energy

Six students expressed this idea during their pre-interviews. This idea was loosely connected to the p-prim that plants need the sun in order to grow. The sun as central to energy was more salient in student post-interviews with 10 of the 11 students expressing the p-prim. Student complexity of understanding ranged during their post-interviews; some students identified that the sun is energy that is needed in an ecosystem whereas others connected the sun to plants and the process of photosynthesis.

Organisms need energy

Six of the eleven students articulated their understanding that organisms need energy during their pre-interview. These p-prims tended to be simple. For example, Fatima stated, “the sun helps us get energy and it goes to the plants.” Fatima noted that humans and plants need energy, but did not specify why the energy is needed. This p-prim progressed and during student post-interviews more students, ten of the eleven, mentioned that organisms need energy, and five of those students expressed that energy flows within the ecosystem. Olivia stated in her post-interview, “Well, the energy flows from the grass to the rabbit, to the rabbit to the snake, and from the snake to the owl.” Demonstrating that this p-prim became more organized and demonstrated a deeper understanding of knowledge concerning energy and organisms.

Rain and clouds are connected to energy

Though they were in the minority, two students related rain and/or clouds to energy during their pre-interviews. Jaylen explained that “rain is the energy for the plant because it makes the plants grow.” He continues to explain that “oxygen, heat, sunlight, and rain give flowers the energy,” indicating that perhaps an underlying connection to photosynthesis may support this connection. During his post-interview Jaylen incorporates additional information, the inclusion of carbon dioxide, with his p-prim about rain and clouds. He states, “sun and water drops help plants grow, and oxygen and carbon dioxide in the air also helps.” Jaylen’s inclusion of carbon dioxide is one step closer to the process of photosynthesis. Ethan, however, was less specific about the connection between rain, rain clouds and energy during his pre-interview. When asked about what he might add to his pre-MBA, Ethan responded, “make like rain clouds for more energy… .”

Electricity is connected to energy

While nearly all students related their discussion of energy exclusively to elements traditionally associated with ecosystems, such as the sun, plants and animals, Devon brings up batteries, lights and light poles as related to energy during his pre-interview. The student does not explicitly use the word electricity, but the elements discussed all related to electricity. In Devon's post-interview he no longer discusses the idea of batteries but includes the p-prim that the sun's rays hit solar panels and the panels can provide light. Devon stated, "Okay, first I drew the solar panels, the sun helps the solar panels and gives energy to the solar panel, the solar panel gives energy to light." This student was the only one to connect the concept of energy to things related to electricity, but the connection points to an area of experiential knowledge from which many students would likely be able to draw.

Matter

The cycling of matter in an ecosystem is another central theme in the Compost curriculum. When asked specifically about matter in their models, six students during their pre-interview either did not directly respond to the question or simply stated, "No." Jaylen responded similarly when questioned about matter, stating, "I don't think I really think about the matter." The number of students who did not speak directly about matter decreased to three at the post-interview.

Everything is matter

Students who responded to the question about matter in the MBA did so with uncertainty at the pre-interview. Several students activated the p-prim that everything is made up of matter, but verbal hedging around statements about matter revealed their tentativeness. For example, Olivia stated, "I mean all of it [items included on her MBA] is matter because everything is made up of matter, but then I don't know." Ethan's response was also shrouded in vagueness. Ethan responded by stating, "Matter is, it's like it takes up like it takes up a big part of this [the MBA] because it is a lot of space taken up in there." Student uncertainty diminished during post-interviews, however, their p-prims did not advance in complexity. Olivia still confirmed "matter makes up everything so matter is everywhere." She, however, expressed this idea with less hesitation than in her pre-interview.

Matter exists in different states

Devon responded to the prompt about matter during his pre-interview by identifying the different states of matter represented in his MBA. Devon's interpretation of the prompt was unique, in that none of the other students identified the states of matter. This does not mean that the other students did not possess the p-prims related to states of matter, but rather that they did not activate this specific p-prim when they were constructing their pre-MBA.

Discussion

The analysis presented here responds to our first research question by outlining how KiP proved to be a useful and applicable framework for understanding and analyzing student knowledge related to ecosystems. Analysis of the pre-interviews and models showed that students bring with them p-prims in distinct topic areas. These p-prims can be leveraged in science classrooms to support student deeper understanding of the content material. Analysis of the post-interviews allowed us to see how student p-prims shifted after having participated in the Compost unit. In response to our second driving question, we now address how student p-prims can be used in order to support curricular design modifications to promote deep learning about the flow of energy and cycling of matter in ecosystems.

Language emphasis on matter

Our analysis revealed that students had an array of p-prims about the flow of energy and the cycling of matter in ecosystems. For example, some students activated p-prims that expressed that matter is everywhere, or that everything is made up of matter consistently from pre- to post-interviews, but did not discuss the process of cycling of matter. Many students also possessed p-prims about decomposers breaking down material and putting it back into the soil. Student knowledge was fragmented, preventing them from connecting the topic of matter to the topic of decomposers breaking down waste. One curriculum-design modification for deeper learning is to include more targeted language in the curriculum to support students in making this connection. The purposeful inclusion of phrases such as "cycling of matter," "rate of decomposition," and "process of decomposition" can be used to focus student attention and engage students in the discussions about matter and the cycling of matter. These phrases can help to make the topic of matter more salient and explicit in student thinking and provide opportunities to incorporate new information with existing p-prims.

Connecting matter to food chains

Analysis of student p-prims revealed that the Compost curriculum did not engage students in the topic of food chains beyond their existing p-prims. As indicated above, students expressed the understanding that organisms are connected to one another in an ecosystem through a mechanism called a food chain. Students focused on the linear nature of the food chain and on organism to organism food consumption with several students connecting energy flow with food consumption. The nature of students' food chain p-prims did not reflect much connection to the cycling of matter in an ecosystem. A design modification which could help students activate, reorganize and extend their p-prims related to matter and food chains would be to incorporate a purposeful emphasis on the composition of organisms and carbon and nitrogen cycling. Activities would center on answering question like: What are we made of? Where does the stuff we are made of come from? Those same questions could be extended to other organisms as well, drawing students into a deeper understanding of the complex relationships between energy flow and matter cycling.

A deeper look at photosynthesis

Students had p-prims that connected the sun to energy and the sun or light to plants. However, the topic of photosynthesis was only introduced formally by one student, Jaylen, and was merely hinted at by others. Photosynthesis is an important topic when discussing the flow of energy in an ecosystem, and also provides an opportunity for a micro-level look at how matter moves in an ecosystem. A new activity could be developed and incorporated into the Compost curriculum that engages students with the topic of photosynthesis diving deeper into the concept of energy flow in an ecosystem. For example, a collaborative photosynthesis model-building activity could push students to follow the atoms and molecules before and beyond the moment of photosynthesis to encourage students to consider the interconnections between energy flow and matter cycling.

Teacher support material

Finally, the identification of student p-prims from both pre- and post-interviews will be important in the development of the teacher support material. By having advanced knowledge of the types of p-prims students bring with them, teachers will be able to aid in students' "re-weaving" (diSessa, 2014). As designers, we can incorporate questions, prompts, and hints into our teacher e-book to provide guidance for teachers when they encounter student p-prims. For example, as evidenced by their interviews students were able to identify different types of decomposers; bacteria, mushrooms, and worms. These decomposers can be identified as either micro or macro. By providing teachers with information on the differences between these decomposers that students can readily identify, teachers can delve deeper with their students on the roles decomposers play in ecosystems and the impact different decomposers have on the process of decomposition. This type of guidance may help students to organize and re-weave their p-prims.

Conclusion

We have suggested that Knowledge in Pieces (KiP) is a suitable way to discuss students' emerging scientific understanding in the domain of ecology. KiP states that students have thousands of loosely organized, highly contextual, and fluid p-prims that shape how students understand scientific concepts. The loose organization of p-prims allows student understanding to be reshaped through phases as new information is gathered. KiP stands in direct contrast to a misconceptions perspective, which views student prior understanding as deeply rooted, resistant to change, and as something that must be overcome in order for scientific understanding to occur (Hammer, 1996; Smith et al., 1994).

Our findings suggest that identifying student p-prims is valuable for designers in order to generate curriculum that encourages deeper understanding of scientific concepts. Student p-prims are not a "road block" to student learning, but a valuable insight into student conceptual understanding (diSessa, 2014). Leveraging student ideas and incorporating them into curriculum encourages students to push their primitive understanding closer to that of experts.

Though the small sample and unique rural context limit the generalization of the specific p-prims uncovered, the successful application of the KiP framework to the ecological topics of flow of energy and cycling of matter is an important addition to the field. The goal of this study was to examine student initial conceptual knowledge related to ecological processes with the KiP framework. The data provided by the interviews offered an in-depth look at the p-prims related to ecological processes that our students brought with them to the classroom. Our design proposals exhibit how that knowledge of student p-prims could be leveraged in curricular design to support deeper understanding. The pursuit of demanding, inquiry-based science instruction for fostering students' deeper understanding of complex science topics should be a major priority for all of us who seek to prepare our students for the challenges of today and the future. The KiP framework provides an important lens for building our own understanding of students' thinking in order to more productively design for and facilitate their knowledge building processes.

Acknowledgements

We thank our participating teacher and students. This material is based upon work supported by the National Science Foundation under Grant No. DRL1418044. Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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