A Review of Practice-Based Literature on Teaching about Interdependent Relationships in Ecosystems to Elementary Students

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INTRODUCTION

Elementary teachers face formidable obstacles when planning and implementing science instruction, including inadequate preparation opportunities, lack of resources, and accountability pressures. Data from the 2012 National Survey of Science and Mathematics Education bear this out (Banilower et al., 2013). Further, the expectations for elementary science instruction were raised to a new level by the Next Generation Science Standards (NGSS Lead States, 2013),the latest in a series of college and career-ready standards released over the last few years. Together with the Common Core State Standards in Reading and Mathematics (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010a, 2010b), they put forth an ambitious vision of what students should know and be able to do in these fields as a result of K–12 education. To realize the vision of excellent science education for all students portrayed in the NGSS, elementary teachers will need to draw on a wide variety of knowledge. Prominent educators and researchers have proposed the existence of a professional knowledge base for teaching, similar to the specialized knowledge bases for medicine and law (Grossman, 1990; Hiebert, Gallimore, & Stigler, 2002; Hill, Rowan, & Ball, 2005; Shulman, 1986). Efforts to articulate the components of such a knowledge base have been underway for over two decades. Some constituent knowledge forms, such as disciplinary content knowledge, are fairly well understood and widely accepted as necessary, but not sufficient, for effective teaching (e.g., Heller, Daehler, Wong, Shinohara, & Miratrix, 2012).

Perhaps the most widely recognized form of specialized knowledge for teaching—and arguably the one with the most potential for helping teachers overcome knowledge-related obstacles—is “pedagogical content knowledge” (PCK), which Shulman (1986) described as an amalgam of pedagogical knowledge (general teaching knowledge) and content knowledge (knowledge of a specific discipline). An oft-cited example is knowledge of an effective strategy for teaching a particular concept; for example, having students slide an object on progressively smoother surfaces to construct an understanding of the idea that an object in motion tends to remain in motion in a straight line unless a force acts on it. Magnusson, Krajcik, and Borko (1999) developed a model of PCK that has strongly influenced conceptualizations of what constitutes PCK in science as well as other disciplines. Recently, a new model of PCK emerged, one that acknowledges both collective and personal aspects of PCK (Gess-Newsome, 2015). In this model, shared or collective PCK is referred to as topic-specific professional knowledge (TSPK). Hypothesized relationships among these and other forms of knowledge are shown in Figure 1.

As illustrated in the model, discrete professional knowledge bases—disciplinary content knowledge chief among them—are the foundation for TSPK. Examples of TSPK include an instructional strategy that has been found through empirical studies to be effective for teaching a specific idea, or recognition of a conceptual difficulty found through assessment studies to be prominent among elementary students. This knowledge can be applied by teachers to their own unique settings and for their own purposes. As teachers take up TSPK—through reading, professional development experiences, discussions with colleagues, reflecting on their practice—and use it in their teaching, it becomes personal PCK.

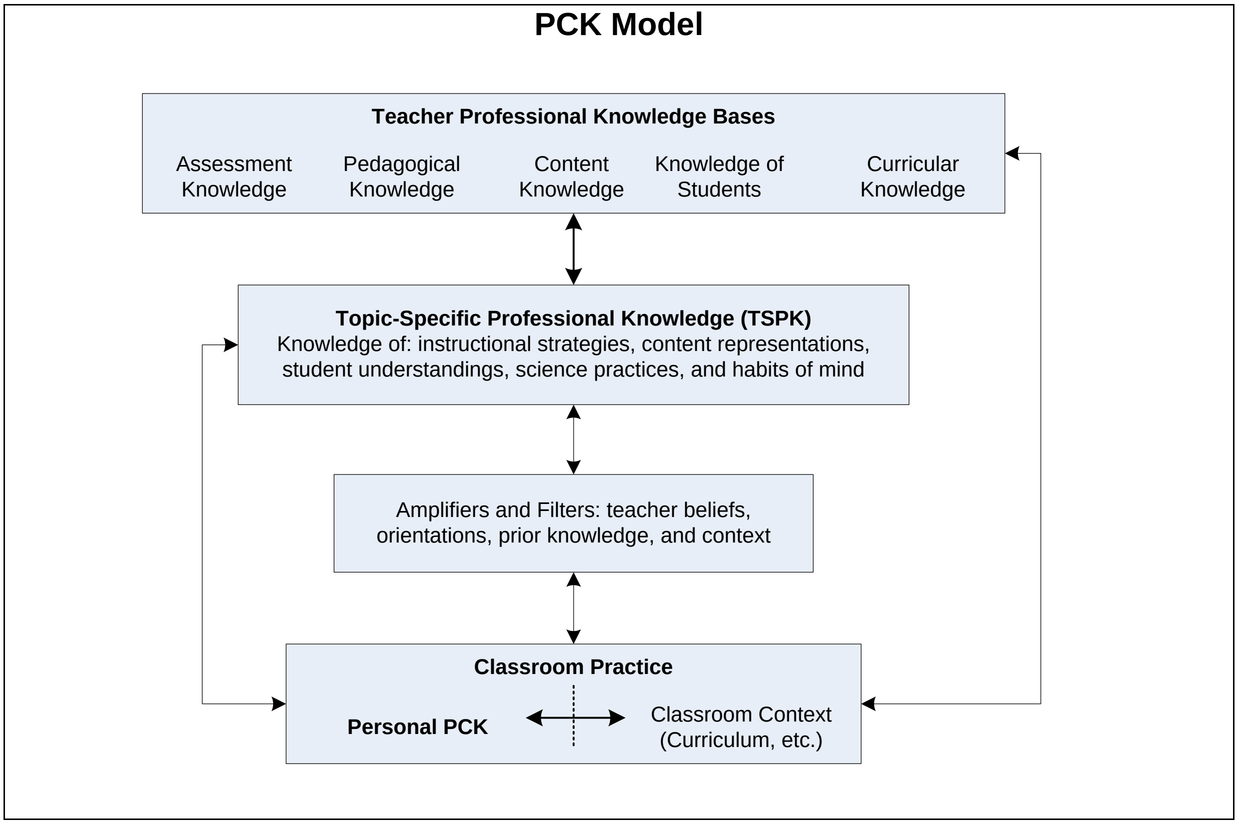

Figure 1

TSPK can help elementary teachers overcome knowledge-related obstacles to science teaching in several ways. Most importantly, TSPK provides a rich resource for helping teachers incorporate what is known about effective teaching of a topic into their instruction (see Figure 2). TSPK can be a valuable instructional planning resource or it can, for example, be the focus of discussion in a teacher study group or professional learning community. Another high-leverage use of TSPK is in instructional materials development (Banilower, Nelson, Trygstad, Smith, & Smith, 2013). Similarly, teacher educators and professional development providers can use TSPK to craft and provide topic-specific support for pre-service and in-service teachers.

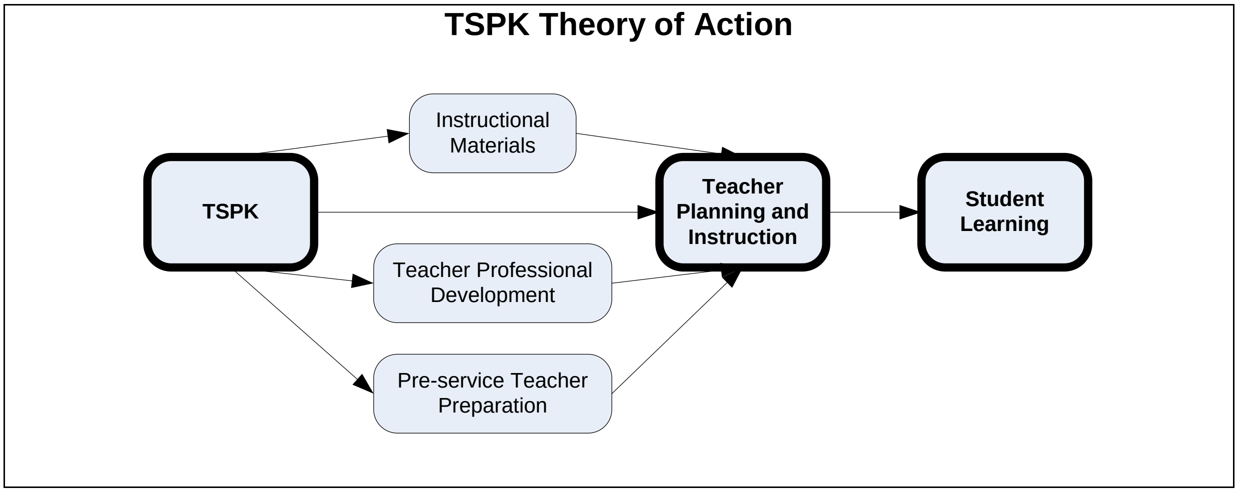

Figure 2

There is a common perception that TSPK is widely available. And although TSPK does exist and has been compiled in a few topics (e.g., empirical research abounds for student thinking about force and motion), many, perhaps most, science topics are not well researched. Even a brief search of the literature illustrates the lack of easily accessible TSPK in many topics. In addition, the literature that does exist is not organized for use by teachers.

With support from the National Science Foundation, Horizon Research, Inc. (HRI) is testing a method for collecting and synthesizing PCK from multiple sources, with the ultimate goal of making the resulting TSPK available to teachers as a support for implementing the NGSS. The method uses three sources: empirical research literature, practice-based literature (e.g., professional journals for classroom teachers), and wisdom of practice (collected by surveying and/or interviewing practitioners).

In this report, we describe the results of a review of practice-based literature related to teaching one topic from the NGSS. Our goal was to determine the nature and extent of PCK for teaching about interdependent relationships in ecosystems at the upper elementary level that could be "extracted" from the practice-based literature. Subsequent reports will describe efforts to synthesize PCK from this source, the empirical literature (i.e., based on research studies), and expert wisdom of practice.

METHODOLOGY

The literature review focused on the NGSS disciplinary core ideas (DCIs) related to Interdependent Relationships in Ecosystems at the fifth grade: 5-LS2.A. The NGSS state the ideas related to interdependence as:

> The food of almost any kind of animal can be traced back to plants. Organisms are related in food webs in which some animals eat plants for food and other animals eat the animals that eat plants. Some organisms, such as fungi and bacteria, break down dead organisms (both plants or plants parts and animals) and therefore operate as "decomposers." Decomposition eventually restores (recycles) some materials back to the soil. Organisms can survive only in environments in which their particular needs are met. A healthy ecosystem is one in which multiple species of different types are each able to meet their needs in a relatively stable web of life. Newly introduced species can damage the balance of an ecosystem (NGSS Lead States, 2013, p. 48).

We rearranged and unpacked some of the ideas in a way that would more easily allow us to organize findings from the literature:

1. The food of almost any kind of organism can be traced back to producers such as plants and algae.
    a. Food provides organisms the materials and energy they need to grow and function.
    b. Producers make their own food *inside themselves* using energy from the sun, and matter from air and water.

2. Organisms in ecosystems are related in food webs.
    a. Consumers get their food by eating other organisms. Some consumers eat producers. Some consumers eat other consumers.
    b. Decomposers, such as bacteria, fungi and earthworms, are consumers that break down dead organisms (or parts of organisms).
    c. Decomposition eventually restores (recycles) some materials back to the environment, making necessary resources available to producers.

3. Organisms can survive only in environments in which their particular needs are met. Environmental conditions include, but are not limited to, light, temperature, moisture, amount of oxygen, nutrient availability, and salinity.

4. A healthy ecosystem is one in which the needs of multiple types of organisms are met in a relatively stable web of life.

5. Natural events and human activity can change the balance or stability of an ecosystem. When the balance, or stability, of an ecosystem changes, the opportunities for different types of organisms to meet their needs can increase or decrease.

We began the literature search by identifying a list of key search terms, such as "ecosystem(s)," "food web," and "student knowledge." The full list of key terms can be found in Table 1. Individually, these terms returned a broad spectrum of results from the search engines (ERIC and

Google Scholar among them); therefore, many of the terms were used in combination in order to narrow the literature to pieces that relate to teaching interdependence in ecosystems at the elementary school level. Two examples include, “ecosystems AND elementary students” and “food web AND misconceptions[1] AND elementary education.” For search terms more likely to yield instructional guidance (e.g., lesson plans, instruction), phrases such as “elementary/secondary education” and “elementary/secondary science” were used to narrow the search.

Table 1
Key Search Terms

Activities	Ecology misconceptions	Elementary student	Predator
Concepts	Ecosystem interdependence(ies)	Food web	Prey
Curriculum	Ecosystem misconceptions	Instruction	Producer
Decomposer	Ecosystem(s)	Learning	Student knowledge
Decomposition	Elementary	Lesson plans	Student thinking
Ecology	Elementary education	Lesson(s)	Understanding

To be included in the review, a piece had to be accessible to teachers for no more than a nominal fee. For this reason, proprietary instructional materials typically adopted by a school or district were excluded from our collection. These included textbooks and kit-based curricula. Unlike the research literature, which consisted primarily of journal articles focused on empirical studies, sources within the practice-based literature varied considerably. Though some pieces were standalone articles within practitioner publications (e.g., *Science and Children, American Biology Teacher*), others were found within comprehensive teacher curriculum guides (without accompanying student materials), published both commercially and by nonprofit organizations. Pieces were initially screened by reading only the abstract or introductory text providing the focus and context. Those that appeared to meet the review criteria (N = 129) were saved in a reference management program. In the case of comprehensive teacher curriculum guides, the entire resource was saved; these were later reviewed for relevant sections.

The project team created a list of tags to be applied as the pieces were read more carefully, and the tags were used to filter the collection. For example, pieces that focused on the content at a high school level or beyond were excluded from the final collection. Because we were most interested in finding PCK related to our targeted ideas about interdependent relationships in ecosystems, we also excluded literature focused on:

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[1] In this report, “misconception” is used to denote any idea that conflicts with accepted scientific ideas about a phenomenon, acknowledging that such ideas are neither good nor bad and may represent a productive step in a student’s learning progression.

- misconceptions or concept development at a level broader than ecosystems (e.g., biology, 5th grade science);
- photosynthesis in the absence of its role in ecosystems; or
- a particular set of organisms (e.g., insects, shrimp, polar bear) when connections to general ecosystem concepts were not evident.

The final pool included 63 pieces, with publication years from 1971 to 2016 (median = 1994).

Once the literature pool was finalized, researchers began coding the kinds of PCK in each piece for teaching about interdependent relationships in ecosystems to upper elementary students. The coding scheme was both *a priori*, based on the Magnusson et al. (1999) model of PCK, and emergent. Magnusson et al. describe discrete forms of PCK, including knowledge of instructional strategies, knowledge of students' understanding of science, and knowledge of science curriculum. In some cases, we elaborated on these forms, for example adding *misconceptions* and *learning progressions* as categories of knowledge of student understanding. A codebook was developed to provide descriptions of each code, rules for when a code should be applied. The codebook is included in the Appendix.

In the next section, we summarize the substantive findings from the practitioner literature.

FINDINGS

As mentioned previously, the search and screening processes yielded 63 pieces of literature, which we organized based on the focus of each piece, forming four broad categories:

- standalone activities (single activities presented apart from a unit);
- collections of activities (several activities but not organized into a coherent unit);
- replacement units (activities that appeared to be intentionally sequenced to build on one another and address specific learning goals); and
- instructional approaches (broad guidance about instruction related to the topic).

Table 2
Article Summaries

Title	Author (Year)	Number of pages	Targeted age/grade level (as described by author(s))
Standalone Activities			
Aquaponics: What a Way to Grow!	Gillan & Raja (2016)	9	Grade 5
Building Ecosystems: Organisms, Energy, and Minerals	Windle, Legato, Strid, & Wallace (1977)	11	Grades 4–5
Collards and Caterpillars	Ashbrook (2007)	3	Early elementary
Crabby Interactions	Jeffery, McCollough, & Moore (2016)	8	Grade 5
Ecological Ouch!	Clapper (1976)	4	Upper elementary
Ecosystem in a Jar	Leager (2007)	3	Grades 3–4
Enhancing Science Instruction through Student-Created PowerPoint Presentations	Gerido & Curran (2014)	5	Grades 4–5
Fire and Ecological Disturbance	Dentzau & Sampson (2011)	8	Not specified
Food for Plants: A Bridging Concept	Keeley (2012)	5	Grade 5
Food Web Forage	Pfaffinger (1999)	4	Grades 3–7
Food Webs and Environmental Disturbance: What's the Connection?	Ford & Smith (1994)	3	Not specified
Is Your Soil Sick?	Sterling & Hargrove (2012)	6	Grades 5–8
iSTEM: A Fibonacci Simple Ecosystem–Prey and Predator.	Garcia (2014)	5	Grades 6–8
Let's Build a Pond!	Winkeljohn & Earl (1982)	2	Grades 3–6
Marine Food Web Simulation	Ogletree (2005)	2	Grades 4–6
Oh, Deer!: Predator and Prey Relationships--Students Make Natural Connections through the Integration of Mathematics and Science	Reeder & Moseley (2006)	7	Not specified
Okay, Kids, Everyone into the Pit!	Belle, Jackson, & Sullivan (1988)	4	Grades 3–8
Our World without Decomposers: How Scary!	Spring & Harr (2014)	10	Grade 5
Pond in a Jar	Allard (1994)	2	Elementary school to graduate school
Roundworm Roundup	Hampton (1991)	3	Not specified
Simulation of a Food Web	Kuhn (1971)	3	Elementary-junior high
Soil Is More than Just Dirt	Taylor & Graves (2010)	7	Not specified
The amazing terrestrial isopods: Third-grade students investigate roly-polies to learn about ecosystems	Dobson & Postema (2014)	8	Grade 3
The Farmer in the Lab	Huss & Baker (2010)	5	Grade 5
The Lorax Readers' Theater: Introducing sustainability with an integrated science and literacy activity	Plankis, Ramsey, Ociepka, & Martin (2016)	7	Grades 4–6

The Use of the Microcomposter to Study the Dynamics of a Mini-Ecosystem	Dubois-Jacques, Saurette, Stoeber, & Gravel (2010)	8	Grade 6
What Happens When an Environment Changes?	Brown, Drury, Gianelloni, & McCoy (2015)	7	Grades 3–5
Collections of Activities			
Branching Out: Forest Studies with Children	Argast & Macdonald (1996)	3	Elementary
Contrasts in Blue: Life on the Caribbean Coral Reef and the Rocky Coast of Maine	Smithsonian Institution (1996)	17	Grades 4–9
Ecosystem explorations	Gunckel (1999)	6	Grade 5
Energy Relationships in Aquatic Environments: A Computer Approach	McLamb & Walton (1987)	4	Not specified
Environmental education activities manual	Stapp & Cox (1974)	764	K–12
Invitations to Interdependence: Caught in the Web. Teacher-Friendly Science Activities with Reproducible Handouts in English and Spanish. Grades 3-5. Living Things Science Series	Camp (1995)	47	Grades 3–5
Living things and environments	Tytler, Haslam, & Peterson (2011)	54	Elementary
Prairie Stamp Activity Guide	Blanchard & Hoofnagle (2001)	18	Grades K–8
Science Action Labs Part 2: Environment	Shevick & Shevick (1995)	64	Grades 4–8
Suggestions for Curriculum Development [And] Handbook Upper Elementary Grades, Part B, 4-6. Environmental Education Interdependence: A Concept Approach. Revised.	King & Long (1976)	102	Grades 4–6
The Growing Classroom: A Garden-Based Science and Nutrition Curriculum for 2nd through 6th Grades. Book 2: Science	Appel, Jaffe, Cadoux, & Murray (1982)	191	Grades 2–6
The Long Island Pine Barrens: A Curriculum & Resource Guide	Long Island Pine Barrens Society (1998)	60	Grades 3–8
The Ocean: Consider the Connections...Educational Activities for Children	Bierce (1985)	98	Elementary
Understanding Ecosystem Management	Smith, Brook, & Tisdale (1994)	8	Not specified
World of Fresh Water: A Resource for Studying Issues of Freshwater Research	Clement, Sigford, Drummond, & Novy (1997)	68	Grades 4–6
Replacement Units			
Alaska Wildlife Week, Upper Elementary Teacher's Guide. Unit 4. We All Need Each Other--The Web of Life.	Quinlan (1986)	50	Elementary
An Activity Guide for Teachers: Everglades National Park. Grades 4-6	De Jong (1991)	222	Grades 4–6
Aquatic Habitats: Exploring Desktop Ponds. Teacher's Guide	Barrett & Willard (1998)	128	Grades 2–6
Causal Patterns in Ecosystems Lessons to Infuse into Ecosystems Units to Enable Deeper Understanding Second Edition	Grotzer, Basca, & Donis (2011)	252	Upper elementary
Child Ecology: A Complete Resource Guide for the Elementary School Teacher	Smith & Others (1974)	244	Grades K–6

Dig In!: Hands-on Soil Investigations	National Science Teachers Association (2001)	129	Grades K–4
Eco-Inquiry: A Guide to Ecological Learning Experiences for the Upper Elementary/Middle Grades.	Hogan (1994)	392	Grades 5–6
Forests and Flowers. A Spring Activity Packet for Third Grade	Jackson Community College (1984)	38	Grade 3
Grasslands. Habitat Ecology Learning Program (HELP). Teachers' Manual	Wildlife Conservation Society (1995a)	149	Grades 4–6
How Nature Works. Habitat Ecology Learning Program (HELP). Teachers' Manual	Wildlife Conservation Society (1995b)	115	Grades 4–6
Teaching Nature in Cities and Towns. Urban Outdoor Biology and Ecology	Vogl & Vogl (1985)	102	Elementary
Instructional Approaches			
Chesapeake Bay Critters	Mackay-Atha (2005)	6	Not specified
Exploring Ecosystems	Fredericks (2004)	16	Grades K–6
Focusing on Function: Thinking below the Surface of Complex Natural Systems	Hmelo-Silver et al. (2008)	9	Middle grades
Go on a ScienceQuest	Long, Drake, & Halychyn (2004)	6	Grades K–4
Hard-To-Teach Science Concepts: A Framework to Support Learners, Grades 3-5.	Koba (2011)	59	Grades 3–5
Indoor Pond Biology	Kunkel (1977)	6	Grade 5
Learning in Virtual Forest: A Forest Ecosystem in the Web-Based Learning Environment	Jussila & Virtanen (2014)	5	Ages 10–13
Tabizi Pythons and Clendro Hawks: Using Imaginary Animals to Achieve Real Knowledge about Ecosystems	Rockow (2007)	7	Middle grades
Teaching Science through a Systems Approach	Llewellyn & Johnson (2008)	6	Middle grades
What Does Culture Have to Do with Teaching Science?	Madden & Joshi (2013)	5	Grade 2

Our findings include PCK in two broad categories—instructional PCK and knowledge about student thinking. In coding PCK from the collection of literature, it became clear that the literature focused primarily on instructional strategies and approaches. We did not frequently encounter instances of student thinking; however, the instances mentioned in the practice-based literature were most often also supported by the empirical literature,[2] suggesting connections between student thinking and instructional design, though these were not always explicit.

A subset of instructional approaches and descriptions of student thinking in the literature appeared to be associated with a specific learning target. First, we summarize our findings regarding these instances, organized by four of the fundamental ideas related to interdependent relationships in ecosystems described earlier. We refer to this type of PCK as "idea specific." In contrast, other findings from the literature cut across several ideas, reflecting the interrelated

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[2] Hayes, M., Plumley, C., Smith, P.S., & Esch, R.K. (December 2016). *A Review of the Research Literature on Teaching about Interdependent Relationships in Ecosystems to Elementary Students*. Retrieved from http://www.horizon-research.com/interdependencelitreview.

nature of these concepts; these are discussed later in this section, following the idea-specific findings. We refer to this type of PCK as "cross idea."

Idea-specific PCK

Producers make food for their growth using light, carbon dioxide from air, and water.

To elicit student ideas about producers making food for their growth, authors suggested asking students simply to consider how plants grow, a process they may not have previously given much thought to. To focus students' attention on what happens as producers grow, Koba suggested:

> *Show a video clip that demonstrates plant growth, making certain to include images that show plant growth from a seed into a mature plant….After the video, ask, "How did the seed change from a seed to a seedling and finally to a sunflower?" Have students create an annotated drawing that shows their thinking.* (2011, p. 62)

Although the literature was heavily focused on instructional strategies, there was some attention to common patterns of student thinking. Several practitioners found that students' initial ideas related to producers were characterized by a general unawareness, including being unaware of producers making their food, as well as the materials used and the process. Similarly, Keeley advised that students may consider plants only as a food source, believing that "plants exist to make food for animals that eat plants" (2012, p. 26).

Another common conception involves the idea that producers take in food from their surroundings, rather than using materials from their surroundings to make food (Hogan, 1994; Koba, 2011). To further students' understanding of producers' requirements for growth and to counter the idea that plants' food comes from the soil, Koba suggested either conducting investigations to explore varied conditions for plant growth in the classroom or using an online simulation. If these misconceptions persist, Koba recommended investigations of plant growth in the absence of soil:

> *Ask students where they think the plant's increasing mass came from. If they think it is the soil, there are several ways you can help dispel this notion. During the lesson, you can sprout a sweet potato in water and occasionally draw students' attention to it. You can also set up a hydroponics station. Ask students how the plant could grow and gain mass even though there is no soil.* (2011, p.62)

Matter and energy flow through ecosystems. Matter provides organisms the materials and energy necessary to function and grow.

The most commonly cited approach for eliciting students' ideas about matter and energy flow involved visual representations of an ecosystem and its trophic relationships. In a later section, we discuss how diagramming an ecosystem often serves as the first step in an extended sequence of instruction designed to target multiple ideas, including examining the effects of natural disturbances (e.g., drought) and those caused by humans (e.g., fertilizer runoff from agriculture). However, in the cases described here, constructing a food chain, food web, or picture of an ecosystem served to gather students' initial ideas about trophic relationships within an ecosystem (Gunckel, 1999; Jackson Community College, 1984). For example, Gunckel (1999) described how students created a mural to hypothesize the organisms and relationships they expected to find in an ecosystem.

Others suggested using focused probing questions to find out what students think organisms need to survive, and to explore students' prior knowledge of trophic relationships (Grotzer, 2009; Hogan, 1994). For example, Hogan suggested posting the following questions on a class chart:

> *Do most animals eat just one thing or many different things?*
> *Does more than one kind of animal eat the same thing?*
> *Will we find more animals that eat plants, or more that eat other animals?* (1994, p. 60)

In addition to serving as a prompt, food web construction tasks appeared in varied forms as an instructional approach where tracing the feeding relationships between organisms was the primary focus. Some focused on a particular location, drawing on students' familiarity of who eats whom in that ecosystem (De Jong, 1991; Smithsonian Institution, 1996); others involved connecting oneself or the foods one eats to a food web or food chain (Smith et al., 1994; Stapp & Cox, 1974; Wildlife Conservation Society, 1995b). Belle (1988) described the use of a game to create a visual representation of a food chain. Grotzer et al. (2011) suggested the use of a computer simulation to model predator-prey relationships

Model ecosystems also appeared in the literature as a means to focus students' attention on the relationships within an ecosystem (Gunckel, 1999; Smith et al., 1994). Gunckel described using a closed terrarium to illustrate feeding relationships and examine the necessary food sources for particular organisms:

> *For example, if a team [of students] adds a spider, which is carnivorous, to their terrarium, they must also supply a fly or other insect for the spider to eat.* (1999, p. 21)

Bringing model ecosystems into the classrooms was not the sole approach to observing organisms as they interact. Others encouraged students to observe relationships in a natural setting through a site visit, if feasible (Bierce, 1985; Gunckel, 1999; Tytler et al., 2011). Ashbrook (2007) detailed somewhat of a hybrid approach, which involved planting collards and raising moths to give students the opportunity to observe a producer-consumer relationship.

Decomposition is the chemical breakdown of dead organisms (or organism parts) performed by some consumers and is essential to a healthy ecosystem.

As a starting point for instruction on decomposition, authors often suggest asking students to consider what happens to organisms' remains (Grotzer, 2009; Koba, 2011; Spring & Harr, 2014). Spring and Harr's elicitation technique draws on students' experiences with "the unwelcomed presence of decomposing organisms in their environment (e.g., rotting food, wilting plants, decaying animals," by asking students "to describe what happens to these organic remains," (2014, p. 29). According to the authors, students' general unawareness of decomposition becomes evident in response to such questions; they describe 5th grade students as "tongue-tied and puzzled" (Spring & Harr, 2014, p. 29).

Relatedly, Hogan describes how students grapple with understanding and explaining the underlying, invisible process of decomposition and the recycling of materials back into the environment:

> *Many children have an intuitive idea that dead plants make soil better for living plants, but their understanding of how this happens can be quite vague…. They imagine a dead plant connecting to the root of a living plant, but do not yet have concepts and images necessary to explain what happens on an invisible level. Understanding nutrient cycling requires being able to imagine and accept that all matter is made of particles that are so tiny that they're impossible to see, even with the most powerful microscopes.* (1994, pp. 261–262)

In a discussion guide, Grotzer calls attention to the importance of revisiting the questions, "What happens to the largest animals when they die? Are they eaten for energy? If so, what eats them?" as student conceptions evolve so that students do not limit their view of decomposers to exclusively serving other organisms:

> *Students may not yet know that the smallest decomposers eat the largest dead animals. They may think that the animals just break down or not realize that decomposers break things down to get energy. They often think of them as doing what they do as a public service to the food web.* (2009, p. 28)

On the other hand, Spring and Harr (2014) mentioned the negative connotation that the word "bacteria" can have for upper elementary students, which may interfere with students' ability to see microbes as beneficial.

Providing opportunities for observation emerged as the primary approach to deepening student understanding of decomposition and decomposers. Opportunities included classroom investigations of organic material over time and outdoor excursions to search for evidence of decomposition; the former was more prevalent. Several authors describe materials, procedures, and suggestions for creating conditions for visible decomposition in a small space (Appel et al., 1982; T. Grotzer et al., 2011; Hogan, 1994; Jackson Community College, 1984; King & Long, 1976; A. Smith & Others, 1974; Spring & Harr, 2014). In-class decomposition investigations were often tied to composting. For example, Appel (1982) describes an activity in which students create "compost bags," make predictions about what will happen to the contents, and then open the bags a month later to observe the conditions of the ingredients and hypothesize about what occurred.

In conjunction with in-class investigations, authors suggest outdoor observations of decomposers at work (Hogan, 1994; Spring & Harr, 2014). Prior to going outdoors, Hogan suggests posing the following questions to orient students to the focus of their observation:

> *What could we see that would tell us if decomposition is occurring?*
>
> *Are some places more likely to have evidence of decomposer action than other places?*
>
> *Where do you think will be the best spots to look for decomposition?* (Hogan, 1994, pp. 187–188)

Spring and Harr (2014) also describe the use of questioning prior to observation to direct students' attention to surroundings that they may have not considered otherwise. For example, asking students, "Why shouldn't these logs be cleaned up? Is there a good reason to leave them there?" to spark conversation about the process of decomposition and how it benefits other organisms (Spring & Harr, 2014, pp. 31–32).

To gauge student understanding of decomposers and their important role in an ecosystem, Spring and Harr (2014) suggest a culminating activity in which students consider how the world would be different in the absence of decomposers. Grotzer et al. also recommend posing questions to help students consider the importance of decomposers; for example:

> *What would happen if dead logs all disappeared instead of being recycled? What might the consequences be?* (2011, p. 70)

Abiotic factors impact organisms' ability to function and survive.

Across the literature, the concept of abiotic factors was addressed most frequently by examining plants' needs for growth and survival, making a connection between this concept with the previously discussed idea about producers' use of materials from their surroundings for growth. Authors suggest prompting students to consider factors affecting plant growth and investigating plants in varied conditions to surface student thinking about the impacts of environmental conditions.

Several activities in the literature involve observation of plants in varied conditions (Appel et al., 1982; Jackson Community College, 1984; Smith & et.al, 1974; Stapp & Cox, 1974).

Others suggest observing or studying a natural area through either outdoor field experiences or research of its living and non-living components (Argast & Macdonald, 1996; Long Island Pine Barrens Society, 1998; Smith & et al., 1974; Stapp & Cox, 1974; Wildlife Conservation Society, 1995b). Others suggest exploring the effects of abiotic factors using in-class investigations (Shevick & Shevick, 1995; S. Smith et al., 1994; Stapp & Cox, 1974). Smith et al. include an investigation designed to illustrate the effects of variation in moisture:

> *Have students observe and describe succession (the series of changes that naturally take place in a community over time) by conducting the following experiment using soil, water, seeds, a plant, and a jar. First, place 5cm of soil in a jar and fill with water to a depth of 7.5 cm. Place the uncovered jar on a windowsill, allowing the contents to settle overnight. Plant an aquatic plant in the jar. As time passes, do not replace water that evaporates from the jar. Once or twice a week, have students add three or four seeds (use mixed birdseed) to the jar. As long as water remains in the jar, the seeds should germinate and then die. Continue adding seeds even after the water evaporates; this evaporation is a metaphor for a warming, dying climate. As the water evaporate, the aquatic plant will die, but the birdseed may find the environment suitable for growth. Begin adding water to represent rainfall. Have students illustrate what they saw happen to their "pond." What did they learn about environmental change?* (1994, p. 38)

Cross-idea PCK

Much of the literature addressing the idea that all populations within an ecosystem are interdependent incorporated previously discussed ideas within the topic (e.g., trophic relationships, the role of producers, the impacts of abiotic factors). Some suggest that students should approach interdependence concepts simultaneously. For example, Fredericks suggests the importance of drawing students' attention to the larger picture, as opposed to discrete ideas:

> *Upper elementary students need to understand that ecology centers both on the various components of nature as well as how the components work together as a whole. Students also need to know that the interactions that take place in a desert ecosystem, for example, share some basic similarities but are also different from those in other ecosystems.* (2004, p. 16)

As shown in the preceding quote, Fredericks also highlights students' need for opportunities to make comparisons among ecosystems in order to develop an understanding of both the underlying principles and locale-specific considerations. Similarly, in an upper elementary curriculum guide, King included the following objective: "To understand the meaning of systems and interdependence and to be able to apply this knowledge to newly encountered material" (1976, p.2). Many instructional approaches found in the literature to address multiple concepts simultaneously included one of the following: using models, engaging students with a scenario of an ecological disturbance, or examining a particular ecosystem.

Given that much of what happens in ecosystems is difficult to conceptualize due to the extensive size of systems and the extended time needed for processes to occur, it is not surprising that modeling was a common approach. Though various models were mentioned, using a food web or a living model (e.g., terrarium, aquarium) was most prevalent. These models appear to offer considerable versatility and potential for teaching several ideas through observation and analysis.

Although many food web activities result in a student-constructed food web, not all of these tasks involved written or pictorial representations. Roleplay and simulations occurred frequently as a means to engage students in visualizing the interdependent nature of ecosystems. One oft-cited activity involves using string, or yarn, to trace connections among organisms (typically with individual students playing the role of a population of organisms—e.g., rabbits) and simulate the effects of disturbances to an ecosystem (Appel et al., 1982; Camp, 1995; Clement et al., 1997; Grotzer et al., 2011; Kuhn, 1971)

> *Using a large ball of yarn, start with water and sunlight and ask what members of the wetland use these things. Connect students with yarn as they demonstrate relationships. Cut the yarn whenever it becomes cumbersome. Eventually it should be clear that all members of the ecosystem are connected. Try tugging on one link of the web and seeing how many students can feel it. If each student who feels the tug pulls on the lines he or she is holding, the original tug will ripple through the whole community just as wetland disturbances affect many organisms. (Clement et al., 1997, p. 28)*

> *As the data is analyzed, each student assumes the role of an organism of the community—one might be a green alga, another a water flea, another a catfish, another a snail, etc. As each relationship is established, a line is strung, e.g., between the "producer" organism and a primary consumer. Other relationships can be established in a similar manner. As the analysis continues, the existing relationships become evidence; one primary consumer may feed upon several producers; a third-order consumer may feed upon several other animals. The complexity of the food web becomes strikingly evident and the visual impact is substantial.* (Kuhn, 1971, p. 832)

In addition, authors often discussed pairing site visits and observations with making a food web (Appel, Jaffe, Cadoux, & Murray, 1982; Barrett & Willard, 1998; Bierce, 1985; Hogan, 1994; Kuhn, 1971; Stapp & Cox, 1974). In some cases, student research of organisms and relationships in a particular natural ecosystem also contributed to creating a web, either replacing or complementing students' observations (Appel et al., 1982; De Jong, 1991; Stapp & Cox, 1974).

Living models, meaning model ecosystems containing live organisms, also emerged as a common method for simultaneously addressing multiple concepts (Allard, 1994; Barrett & Willard, 1998; Clement et al., 1997; Hmelo-Silver et al., 2008; Kunkel, 1977; Shevick & Shevick, 1995; A. Smith & Others, 1974; Stapp & Cox, 1974). Classroom aquaria and terraria appear to offer substantial fodder for students' exploration of interdependent relationships in ecosystems. Referring to a "pond in a jar" activity, Allard highlighted several potential investigations, including varying light conditions and introducing pollutants (1994, p.372). Similarly, Kunkel (1977) detailed a year-long program titled, "Indoor Pond Biology" (1977, p.342). Hmelo-Silver and colleagues (2008) also outlined an approach that combines the use of aquaria with a computer-simulated model, which allows students to investigate the effects of abiotic factors or population increases.

Another common approach involves engaging students in scenarios; this approach appeared in numerous forms in the literature, including roleplay simulations, thought experiments, online simulations, and videos. For example, Clapper (1976) describes an activity in which several students represent organisms in an ecosystem and one classmate reads a situation from a card; the students acting as organisms then express the effect that the situation, most of which involve human activity, will have on them. Reeder and Moseley (2006) described the potential for integrating mathematics and science through a version of the widely used "Oh Deer!" roleplay activity in which students act as deer populations and collect data to reflect on fluctuations and balance within an ecosystem. Another author described the use of "Oh Deer!" to help students understand that a decline in population does not equate to extinction:

> *Students play "Oh Deer!" (Dalton, 1992), an interactive game that demonstrates what happens to a population of animals when there are more animals than the ecosystem can support….Students sometimes have the misconception that if the population of a species declines, extinction will follow. This activity shows students that populations can decline and then rebound, without leading to extinction. At the end of this period I talk about the limitations of this activity as a model for an ecosystem…* (Rockow, 2007, p. 19)

In addition, practitioners find it useful to introduce an ecological disturbance scenario in order to stimulate student thinking about effects on an ecosystem and examine the extent to which students trace the effects through the populations in an ecosystem. Authors described instances of using hypothetical (De Jong, 1991; Wildlife Conservation Society, 1995b) or historical (Appel et al., 1982; Dentzau & Sampson, 2011; Grotzer et al., 2011) disturbances in specific locations to further examine effects and make connections among populations within an ecosystem. Scenarios from the literature included both natural events and human-related disturbances; examples of the latter follow:

> *A luxury hotel resort is being proposed for an open, natural space along the beach front at Flamingo. This is located inside Everglades National Park. What are your ideas about what happens when a space like this is changed? (De Jong, 1991, p. 39)*
>
> *How might the damming of rivers for water power and water storage upset the ecosystem of the river? (Smith et al., 1974, p. 224)*
>
> *Show the class a picture of a field (wild grasses, bushes, flowers). Ask them to guess what changes will occur if the field is used for growing crops. (The children should see that some living things will be removed and replaced with others, selected by humans.) (King & Long, 1976, p. 6)*

Combining the model and scenario approaches, McLamb discussed the affordances of virtual simulations in examining interdependent relationships:

> *The computer can provide, as a textbook does, basic information on biotic communities, food webs, trophic levels, and the interaction of living and nonliving elements in the community. The computer, however, can take it one step farther and simulate the community and the interaction of the elements. Students can manipulate the data in many ways, such as varying the size of populations and the quantity of important nutrients, or they can introduce pollutants into the system. The computer can digest these numbers and crank out charts or graphs illustrating changes occurring over time in the community. In a one-hour class period, students could run dozens of experiments and alter several variables in each. (1987, p. 14)*

Examining a particular ecosystem—that is, observing, or researching an ecosystem and its components, and situating instructional activities in that ecosystem—emerged as another common instructional approach in the literature. One example is a comprehensive unit guide designed by the Long Island Pine Barrens Society (1998) to integrate classroom investigations with outdoor experiences related to the Long Island Pine Barrens. This guide includes the string food web simulation described previously, in which all organisms are native to this particular ecosystem (e.g., Pitch Pine, Tiger Beetle, Red Fox). Another example is the Smithsonian Institution's Art to Zoo publication (1996), which features instructional resources designed to contrast the coral reef of the Caribbean and the rocky coast of Maine. Within these activities, students examine trophic relationships and consider the impacts of both biotic and abiotic factors.

Again, what is common among these three approaches—creating and observing model ecosystems, engaging in scenarios, and examining a particular ecosystem—is their goal of engaging students with multiple ideas simultaneously, with the intent of developing coherent understanding of broad interdependence concepts. In addition, these approaches can be used in a complementary manner. For example, as described above, by creating and analyzing a food web, students can conceptualize feeding relationships between populations and use this understanding to make predictions about the effects of an ecological disturbance. Similarly, when focusing their study on a particular ecosystem, students can model relationships between organisms as well as the relationships that exist between organisms and abiotic factors in the environment.

SUMMARY

Sources within the practice-based literature varied considerably in form, ranging from standalone activities to comprehensive units, published both commercially and by nonprofit organizations. Our findings from these sources can be parsed into two broad categories—instructional PCK and knowledge about student thinking. In coding PCK from the collection of literature, it became clear that the literature focused primarily on instructional strategies and approaches. There were some references to student thinking within these pieces; however, even when present, connections between student thinking and instructional design were not always explicit.

Another dimension of coding involved relating our findings to the ideas we were targeting within the broader topic of interdependent relationships in ecosystems. We found that a subset of instructional PCK and descriptions of student thinking in the literature could be tied to one of four fundamental ideas that we identified:

1. Producers make food for their growth using light, carbon dioxide from air, and water.
2. Matter and energy flow through ecosystems. Matter provides organisms the materials and energy necessary to function and grow.
3. Decomposition is the chemical breakdown of dead organisms (or organism parts) performed by some consumers and is essential to a healthy ecosystem.
4. Abiotic factors impact organisms' ability to function and survive.

Idea-specific findings often took the form of targeted prompts intended to elicit student thinking about one of these concepts. Investigations with varying conditions were also common for examining producers' needs, decomposition processes, and the impacts of abiotic factors.

Other findings cut across several ideas, reflecting the interrelated nature of these concepts. Practitioners often found it useful to draw on students' knowledge of the previously discussed ideas when teaching about how all populations within an ecosystem are interdependent. Therefore, much of the literature to discuss the concept of interdependence more broadly included instructional approaches intended to address multiple ideas simultaneously. Instructional approaches of this type included creating and observing model ecosystems, engaging in scenarios, and examining a particular ecosystem.

Not surprisingly, because of the interconnectedness of the concepts, overlap exists between these holistic approaches and those described in the context of idea-specific findings; however, the approaches differ in terms of intended purpose. The former aims to develop a coherent understanding of broad interdependence concepts, whereas the latter focused on deepening conceptual understanding at a smaller grain size.

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APPENDIX

PCK Extraction Codebook

Code	Description	Extraction Rules	Confidence Rating
Misconception	Misconceptions are student ideas that are in conflict with accepted scientific ideas. Misconceptions typically arise from students' interaction with the physical world around them. A common misconception is that air does not have mass because they can't "feel" it. Misconceptions are neither good nor bad, but they do tend to be deeply ingrained in students' thinking. Some are part of a learning progression for a topic, suggesting that many students will have the misconception at some point as they develop full understanding.	Extract all misconceptions from an article, even if identifying misconceptions was not the intent of the study. Can modify or paraphrase article text for clarity, brevity. For now, lump missing conceptions with misconceptions. Capture related misconceptions separately when possible. When present, capture the cognitive source along with the misconception.	The confidence rating is about how confident we are that this misconception is widespread among 5th grade students based on the study in the article. If the point of a study was to identify student misconceptions and the article fares well in the rapid SoE review, the misconception gets a high confidence rating. All other misconceptions get a low confidence rating. NOTE: when we synthesize across studies, a misconception that shows up several times with a low rating may receive a high rating based on the accumulation of evidence.

Code	Description	Extraction Rules	Confidence Rating
Misinformation	In contrast to misconceptions, misinformation is an incorrect fact not derived from every day experience with the physical world. For example, students might think that water freezes at 32 degrees Celsius. Students' misinformation is probably not as deeply ingrained in their thinking as misconceptions are.	Extract all misinformation from an article, even if identifying misinformation was not the intent of the study.	The confidence rating is about how confident we are that this misinformation is widespread among 5th grade students based on the study in the article. If the point of a study was to identify student misinformation and the article fares well in the rapid SoE review, the misinformation gets a high confidence rating. All other misinformation gets a low confidence rating. NOTE: when we synthesize across studies, misinformation that shows up several times with a low rating may receive a high rating based on the accumulation of evidence.
Idea-level Consideration	Teaching tips are pieces of advice for teachers and are bigger than an individual activity, things that can be useful for teachers to know when teaching the topic. For example, "Investigating the expansion and compression of air is important for students' understanding of the concept of empty space between particles." NOTE: If a tip can be associated with all big ideas in the topic, it should be coded as a unit-level consideration instead (see below).	Extract all idea-level considerations from an article, even if identifying tips was not the intent of the study.	If the point of a study was to identify teaching tips and the article fares well in the rapid SoE review, the tip gets a high confidence rating. All other tips get a low confidence rating. NOTE: when we synthesize across studies, a tip that shows up several times with a low rating may receive a high rating based on the accumulation of evidence.

Code	Description	Extraction Rules	Confidence Rating
Unit-level Consideration	Unit-level considerations (ULCs) are broader than teaching tips and apply to the entire unit, but they should not be broader than the unit (the latter might actually be pedagogical knowledge instead of PCK). For example, “Having students interact with computer simulations that depict particle-level representations of matter can help students understand the particle model of matter.” Code a ULC to all big ideas in the topic.	Extract all ULCs from an article, even if identifying ULCs was not the intent of the study.	If the point of a study was to identify ULCs and the article fares well in the rapid SoE review, the ULC gets a high confidence rating. All other ULCs get a low confidence rating. NOTE: when we synthesize across studies, a ULC that shows up several times with a low rating may receive a high rating based on the accumulation of evidence.
Prompt	Prompts are questions or tasks that teachers would pose to their students in order to elicit their thinking in writing or orally to use for formative purposes. (Some prompts that are appropriate for research purposes (used in interviews, etc.) may be inappropriate for classroom use.)	Extract a prompt if the reviewer can envision a teacher using it with students as is. The “bar” for modifying prompts from article text is higher than that for misconceptions. If prompts that accompany activities or activity seeds can stand independently, capture as prompts. If not, don’t.	The confidence in a prompt is based entirely on the content of the prompt (e.g., how well aligned it is with the idea, how “usable” it is by a teacher), as judged by the reviewer. For example, a prompt that contains wording that may be inaccessible for students would receive a low confidence rating.

Code	Description	Extraction Rules	Confidence Rating
Instructional Activity	Instructional activities are stand-alone, ready-to-use activities that teachers can use in their instruction "as is" with no additional written materials or training. Their purpose is to develop understanding of a big idea. That is, the article should provide enough information so that teachers are able to implement the activity in their classrooms. The learning goal should be explicit or easily inferred. NOTE: Eventually, we will categorize the activities into more general instructional strategies, such as lab experiments, simulations, readings.	Extract an instructional activity if a teacher can use it as is—i.e., it has sufficient context and instructions.	If the point of the article was to investigate the impact of an instructional activity, the confidence rating will be based on the findings of the article and a rapid SoE. If the instructional activity was incidental, the confidence rating will be low. If the article explicitly investigates the efficacy of an entire unit and uses an individual activity to illustrate the material, the activity would receive a low rating.
Activity Seed	Not a ready-to-use instructional activity, but a fleshed out idea for an activity. The seed must have enough description to determine that it fits some big idea(s) and to give a reasonable expectation that teachers could develop it into an activity.	Do not capture if seed is unsuccessful in implementation or in need of substantial modifications in order to be helpful	In order to have a high confidence rating, an activity seed must meet all three of the following criteria: • Is it explained in a way that is clear and accessible to teachers? • Are students likely to learn targeted content from it? • Is it feasible? (time required, materials required)

Code	Description	Extraction Rules	Confidence Rating
Summative Assessment Activity	Summative assessment activities are stand-alone, ready-to-use activities that teachers can use in their instruction to evaluate students.	Extract an assessment if a teacher can use it as is--i.e., it has sufficient context and instructions. Briefly summarize the form and substance of the assessment, and if there's a rubric, describe how it's structured, what kinds of factors it takes into account.	1. If the assessment does not have reliability and validity info, it should receive a LOW rating. (NOTE: if the reliability and validity info are in another article, the assessment should be extracted from that article.) 2. If the assessment does have reliability and validity info, the rating should be based on that information. Reliability should be above 0.7, and there should be at least one form of validity evidence.
Common Student Experiences	Common student experiences are things that a teacher can capitalize on in instruction, knowing that there is a good chance that most students have similar experiences. For example, most 5th grade students will have firsthand experience with an inflated balloon expanding or contracting based on temperature. Most have also observed a puddle disappear over time. Common student experiences may be keyed to one big idea or more than one.	Extract a common student experience if there is evidence in the article that most students come to instruction with the experience. An article that describes what just one student has experienced is not sufficient. Do not include previous instruction experiences.	The confidence rating is based on a rapid SoE review.

Code	Description	Extraction Rules	Confidence Rating
Developmental Challenge	Developmental challenges are things that students struggle with that are broader than misconceptions. For example, 5th grade students and younger may struggle to accept the existence of matter that is too small to see. Developmental challenges may be keyed to one big idea or more than one. Some developmental challenges may have associated ULCs. For example, we think that kids do not apply explanatory frameworks consistently, but rather that it is context specific (e.g., students may understand the particle model in the context of boiling water, but will not apply it to condensation on a cold drink can). The unit-level consideration is that teachers can't assume that just because kids use the particle model appropriately in one context, they will use it appropriately in another.	Extract a developmental challenge if there is evidence in the article that most students come to instruction with the challenge.	The confidence rating is based on a rapid SoE review.
Learning Progression	A learning progression will probably be identified explicitly in an article. A learning progression is at the topic level, so we do not need to code to individual big ideas. All misconceptions in a learning progression can be coded with the progression.	Extract a learning progression if the article describes a sequence of increasingly sophisticated and scientifically accurate understandings and skills within a domain that learners develop over several years.	The confidence rating is based on a rapid SoE review.