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Promoting Prospective Elementary Teachers' Learning to Use Formative Assessment for Life Science Instruction

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Abstract To support elementary students' learning of core, standards-based life science concepts highlighted in the *Next Generation Science Standards*, prospective elementary teachers should develop an understanding of life science concepts and learn to apply their content knowledge in instructional practice to craft elementary science learning environments grounded in students' thinking. To do so, teachers must learn to use high-leverage instructional practices, such as formative assessment, to engage students in scientific practices and connect instruction to students' ideas. However, teachers may not understand formative assessment or possess sufficient science content knowledge to effectively engage in related instructional practices. To address these needs, we developed and conducted research within an innovative course for preservice elementary teachers built upon two pillars—life science concepts and formative assessment. An embedded mixed methods study was used to evaluate the effect of the intervention on preservice teachers' (n = 49) content knowledge and ability to engage in formative assessment practices for science. Findings showed that increased life content knowledge over the semester helped preservice teachers engage more productively in anticipating and evaluating students' ideas, but not in identifying effective instructional strategies to respond to those ideas.

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Introduction

Past research has shown that elementary students hold a variety of alternative ideas about core life science concepts (e.g., Anderson, Ellis, & Jones, 2014; Barman, Stein, McNair, & Barman, 2006; Grotzer & Basca, 2003) emphasized in the *Next Generation Science Standards* (NGSS Lead States, 2013). Effective elementary science learning environments should provide opportunities for students to recognize, expand, and refine their understanding of these and other standards-based science topics (National Research Council [NRC], 2007). Formative assessment is a classroom practice grounded in contemporary theoretical perspectives on teaching and learning that places students' ideas and thinking as the foundation of instruction. Teachers' use of formative assessment practices has been shown to lead to significant gains in students' science learning (Ruiz-Primo & Furtak, 2006). However, past research has shown that elementary teachers may not understand formative assessment or possess sufficient science content knowledge to engage in the practice effectively (e.g., Coffey, Hammer, Levin, & Grant, 2011). As a result, the use of formative assessment within elementary science classrooms is not widespread (Hammer, Goldberg, & Fargason, 2012; Morrison, 2013; Otero & Nathan, 2008).

Teachers' abilities to foster effective science learning environments grounded in students' thinking is dependent on teachers' understanding of how students learn, their own knowledge of disciplinary content, and their pedagogical content knowledge (Heritage, Kim, Vendlinski, & Herman, 2009). Prospective science teachers should learn essential science concepts and how to effectively respond to their students' thinking through instruction. However, the limitations of elementary teachers' science subject matter knowledge are well-documented and preservice elementary teachers are afforded few opportunities to integrate their knowledge of disciplinary content with effective elementary science pedagogy (Haefner & Zembal-Saul, 2004; Rice, 2005). Novel approaches are therefore required to support elementary teachers' developing subject matter knowledge for teaching (Ball, Thames, & Phelps, 2008).

To address these needs, we developed a new course for preservice elementary teachers built upon two pillars—life science content and formative assessment—and aligned with the *Next Generation Science Standards* (NGSS Lead States, 2013). This combined focus allowed preservice teachers to learn to employ their developing life science content knowledge to identify trends in elementary students' thinking and propose instructional next steps which are both critical practices of formative assessment linked to significant gains in students' science learning (Ruiz-Primo & Furtak, 2006). To study the effect of the course as an intervention, we asked the following research questions:

1. Does greater content knowledge enable preservice teachers to more effectively engage in formative assessment for science?
2. How do preservice elementary teachers draw upon their content knowledge to anticipate and evaluate evidence of students' thinking?
3. How do preservice elementary teachers draw upon their content knowledge to reason about instructional next steps?

Significance

Elementary teachers' science subject matter knowledge is often limited and this may inhibit their ability to engage effectively in science instruction (Haefner & Zembal-Saul, 2004; Rice, 2005). Recent research has called for increased attention to the subject-specificity of formative assessment practices (Coffey et al., 2011). Prior studies have explored life science courses designed for preservice elementary teachers (Friedrichsen, 2001; Haefner, Friedrichsen, & Zembal-Saul, 2006; Weld & Funk, 2005) and preservice teachers learning to engage in formative assessment (Buck, Trauth-Nare, & Kaftan, 2010; Kohler, Henning, & Usma-Wilches, 2008; Levin, Hammer, & Coffey, 2009; Otero, 2006; Talanquer, Tomanek, & Novodvorsky, 2013). However, more work is needed to determine the effect of integrating an emphasis on disciplinary content, in this case life science concepts, with "high-leverage" instructional strategies which are those that focus on student learning and are "most valuable for teachers to be able to learn and carry out" (Ball & Forzani, 2009, p. 509). The focus here is on formative assessment and how these two factors of formative assessment and life science concepts influence preservice teachers' pedagogical reasoning about students' thinking. This study addresses key gaps in existing research, illustrating (a) relationships between elementary teachers' disciplinary knowledge and formative assessment practices and (b) the ways in which they anticipate, evaluate, and use students' ideas to inform their science instruction. It has important implications for the preparation and support of elementary teachers of science through teacher education and, more distantly, professional development and curriculum materials design.

Theoretical Foundations

Elementary students bring preexisting ideas about the natural world, constructed from experiences in their daily lives, with them when they enter science classrooms (Donovan & Bransford, 2005). These ideas may not be scientifically accurate and may need to be challenged, expanded, or refined. To that end, elementary science learning environments should be designed to embody core tenets of contemporary learning theory, including opportunities to engage in scientific practices (NGSS Lead States, 2013) such as questioning, argument, explanation, and modeling, to make sense of phenomena. Instruction in effectively designed science learning environments should be responsive to students' ideas, so as to help students "construct understanding of scientific concepts, reason scientifically, appreciate the

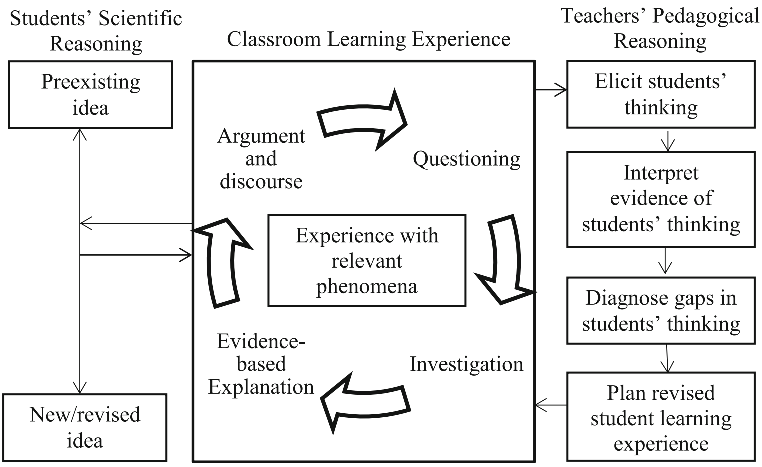

Fig. 1 Relationship between responsive instruction and students' science learning

nature of science, and engage in scientific practices" (Levin et al., 2009, p. 152). Teachers must elicit and interpret evidence of students' thinking, identify gaps in student understanding, and implement instruction that targets those gaps. Teachers' pedagogical reasoning and students' scientific reasoning both influence and are influenced by the learning environment. This student-responsive perspective on learning and instruction aligns directly with current views on science learning and can directly impact students' developing understanding of natural phenomena. A conceptual framework for this relationship, which serves as the theoretical and analytical frame for the study, is shown in Fig. 1.

What is Formative Assessment?

An important way to elicit and respond to students' ideas is through formative assessment. Formative assessment is an approach to responsive science instruction that allows teachers to engage with individual students' ideas, take individual student progress into account, and engage their thinking through instruction (Bell & Cowie, 2001; Coffey et al., 2011). Formative assessment involves concrete steps, such as (a) anticipating and eliciting students' ideas, (b) evaluating students' ideas, and (c) crafting next steps in instruction that account for students' ideas and support students' learning. Formative assessment in the classroom can be "on-the-fly," "planned-for," or "curriculum-embedded" (Shavelson et al., 2008). In the current study, the focus is on "planned for" formative assessment in which teachers examine student work samples from predeveloped prompts designed to be used within the scope and sequence of fully developed curricular units for elementary science. It is one example of a "high-leverage" instructional practice that can significantly shape the nature of formal learning environments (Ball & Forzani, 2009). Past research has shown that formative assessment can lead to significant student learning gains (Ruiz-Primo & Furtak, 2006).

Research on Preservice Teachers and Responsive Science Instruction

In order to create science learning environments that are responsive to students' thinking, preservice teachers must develop content knowledge and pedagogical content knowledge which, taken together, constitute subject matter knowledge for teaching (Ball et al., 2008). This includes not only identifying the prior knowledge of elementary students and how they build knowledge of science content but also developing their own understanding of disciplinary content and how to foreground those concepts in effective experiences for students (Coffey et al., 2011; Heritage et al., 2009). However, preservice teachers often struggle with formative assessment for science. They tend to have limited views of what constitutes elementary students' prior knowledge (Buck et al., 2010; Otero & Nathan, 2008). They often consider students' knowledge in terms of "get it or don't" conceptions which has consequences for how they consider responding to their students' thinking (Otero, 2006). In addition, when they evaluate students' ideas, they describe what students said in the student work more often than they infer understanding or misunderstanding and typically do not focus on the extent to which students' have made sense of the topic (Talanquer, Bolger, & Tomanek, 2015). If they prioritize eliciting student's prior knowledge and/or gaps in understanding, they often do not identify the importance of instruction that responds to these ideas and needs, nor provide the type of feedback and scaffolding that allows students to build knowledge (Buck et al., 2010).

Past work has shown that prospective teachers need opportunities to engage and reflect on learning strategies such as formative assessment during their teacher preparation programs (Kohler et al., 2008). Supporting preservice teachers to learn how to employ formative assessment in ways that go beyond simply deciding whether students "get it or don't" requires a focus within teacher education on the way and the context in which students learn science (Levin et al., 2009). Research suggests that specific types of experiences in teacher education programs can support preservice teachers to expand their knowledge of classroom assessment, including engaging in assessment tasks that mirror those within authentic elementary science learning environments and participating in professional dialogues with colleagues at various points along the teacher professional continuum (Buck et al., 2010; Graham, 2005; Otero & Nathan, 2008; Talanquer et al., 2013). This includes opportunities to elicit and identify elementary students' ideas, consider the particular aspects of student ideas that require action, and engage with the practices of formative assessment to support students' knowledge building.

In addition, prospective elementary teachers need support to learn essential science concepts including those designed to support students' learning in the life sciences (Haefner & Zembal-Saul, 2004; Nowicki, Sullivan-Watts, Shim, Young, & Pockalny, 2013). Prior research suggests that elementary teachers, including preservice teachers, may not possess sufficient science content knowledge to engage in the practice of formative assessment effectively (Buck et al., 2010; Coffey et al., 2011; Falk, 2011; Heritage et al., 2009; Morrison, 2013; Otero & Nathan, 2008). They may view disciplinary content as no more than "a body of correct information, centered on terminology and selected in advance as lesson objectives" (Coffey et al., 2011, p. 1114). Specifically for this study, elementary teachers have been shown to have some of the same alternative conceptions about core life science concepts as elementary and middle school students (Krall, Lott, & Wymer, 2009). As a result, novel interventions are required to help prospective elementary teachers develop and use their subject matter knowledge for teaching to support students' learning of life science concepts.

Study Design and Methods

We used an embedded mixed methods design (Caracelli & Greene, 1997) in which quantitative and qualitative research methods were embedded within the larger course development process (Cresswell & Clark, 2011). This approach allowed us to collect multiple forms of data within a newly developed course, utilize varied methods of data analysis, and merge the findings to reach a greater understanding of the effect of the course on preservice teachers' content knowledge and formative assessment practices.

Context and Participants

The study involved 49 preservice elementary teachers enrolled in an undergraduate course that integrated life science content with instructional methods. The preservice teachers were junior and senior undergraduate students enrolled in a 3-year elementary education program at a large, Midwestern university. All 49 participants were from Midwestern states; 45 were female and four were male. Only one participant identified her area of specialization as science, while four indicated social studies, 11 indicated maths, and 42 indicated language arts/reading.

The New Elementary Life Science Instructional Methods Course

The purpose of the new course (see also Forbes, Sabel, & Zangori (in press) for a full description of the course itself), which was designed to integrate life science content with pedagogy, was to provide prospective elementary teachers with the necessary tools to develop a robust understanding of standards-based life science concepts, opportunities to implement elementary science curriculum materials to engage in effective instruction about these life science concepts, and opportunities to connect the relevant pieces of content knowledge they will need to understand to teach students with national and local standards and research on students' ideas. Emphasis was placed on engaging learners in constructing knowledge through scientific inquiry and scientific practices, such as questioning, investigation, explanation, argument, and modeling (NGSS Lead States, 2013). A major focus of the course was on formative assessment which allowed preservice teachers to use their knowledge of life science concepts as they evaluated elementary students' science understanding and developed instructional next steps to address trends in students' ideas.

The course consisted of a weekly whole-class meeting that focused on life science content and small-group (12–20 students each) methods labs that focused on instructional strategies that preservice teachers would use in elementary science classrooms. The life science content was selected to align with curriculum topic study (CTS; Keeley, 2005), a set of tools and resources that allow teachers to focus on curriculum, instruction, assessment, and teacher content knowledge around a particular science topic. CTS templates provide teachers with direction to resources that allow them to incorporate content knowledge with science standards and research on students' ideas. In the context of the course, we used CTS with preservice teachers as a way to connect the relevant pieces of content knowledge to research on elementary students' ideas and to national standards. The preservice teachers completed one CTS guide each week (15 total) that aligned with the life science topics emphasized in the class.

Data Collection

The data for this study consisted of course-related assessments and artifacts, as well as interviews. Each preservice teacher in the course (N = 49) completed an assessment of their life science content knowledge at the beginning and end of the semester. Multiple-choice assessment items were selected from the AAAS assessment item bank (AAAS Project 2061, 2013) which were specifically developed to align with CTS topics and to be used for administration with different groups of learners, including teachers. The particular items selected for the exam aligned with each of the weekly life science topics and CTS assignments in the course.

Preservice teachers also completed three formative assessment assignments that aligned with relevant CTS topics. In these assignments, they were required to engage in a series of tasks and questions that elicited their pedagogical reasoning about elementary science instruction (Table 1). Preservice teachers were first asked to answer questions related to their content knowledge about the particular assignment topic. They then reviewed an elementary science lesson plan provided by the instructors and were asked to anticipate both ideas and challenges students might have with understanding the key concept of the lesson. Next, preservice teachers examined actual elementary student work from the science lesson, which was provided by the instructors (obtained from other project work in elementary classrooms). Preservice teachers were asked to evaluate sample artifacts from elementary students to identify trends in student thinking. Finally, they were asked to propose hypothetical instructional next steps they might use to address any gaps they identified in elementary students' understanding and to provide rationale for their decisions. These assignments allowed preservice teachers to engage in formative assessment with existing curriculum materials and to evaluate real responses from elementary students. All questions preservice teachers responded to on these assignments are included as a part of the rubric in the "Appendix".

Finally, we conducted semi-structured, reflective grounded interviews with a subset of purposefully selected (Merriam, 2009) students following the FA assignments. Five students were interviewed after each of the three assignments

Table 1 Formative assessment assignment descriptions

Assignment no.	Content	Key concept	Student prompt	Student response format
1	Seed dispersal	Seeds can be dispersed in many different ways based on their physical characteristics	How does this seed [picture included] called a cocklebur travel? How do you think it travels this way?	Written
2	Skeletal system	Bones have three major functions in the human body: support, protection, and locomotion	(a) What are the three main functions of a skeleton? (b) The skull is a hollow case, made of bony plates. Which of the functions listed above is the primary function of the skull?	Written
3	Habitats	Crayfish habitats must include clean, cool water; food; and shelter. These are what the animal requires to live in its habitat	(a) Draw a habitat that would be suitable for several crayfish and label the objects you draw. (b) What basic needs are supplied by the objects in your drawing? (c) What basic need(s) does	Labeled diagram

with an additional five students that varied for each of the three assignments (N = 10 interviews per assignment, N = 30 total). Each interview lasted 15–20 min and was used to engage preservice teachers in thinking about their processes for engaging in formative assessment and to elicit their ideas on each particular assignment in more depth. The interviews were audio-recorded and transcribed for analysis.

Data Analysis

Quantitative Analysis

The pre- and post-tests were scored and used for subsequent statistical analysis. The three formative assessment assignments were scored using a project-developed rubric aligned with each of the questions on the assignment that examined how well preservice teachers (a) anticipated student ideas, (b) evaluated student responses, and (c) proposed instructional next steps. Within each of these categories, the rubric further delineated the degree of detail and accuracy the preservice teachers included in describing trends or lessons and connecting to the key concept of the lesson. The rubric consisted of a five point scale (0–4). The scoring rubric used for research purposes was not the same rubric that was used for grading the assignments for the class. The scoring rubric was aligned with the underlying theoretical perspectives of the study and was designed to capture how preservice teachers interpreted, described, and diagnosed students' ideas. See the "Appendix" for the full rubric used to score the assignments.

The rubric went through multiple rounds of revision until two scorers were able to obtain consistent scores. The final revision round was used to establish the reliability and consistency of the rubric. Two researchers scored a 10 % subset of the assignments (n = 15) and Cronbach's alpha was calculated as 0.982. This high interrater reliability justified scoring on all remaining assignments to be completed by the first author alone (Miles, Huberman, & Saldaña, 2014). The high interrater reliability also provided evidence that the levels on the rubric were clear and distinguishable for scoring purposes. We calculated a total score for each assignment, as well as subscores for each major component: *anticipating* student ideas, *evaluating* student understanding, and choosing *next steps* in instruction. The pre- and post-test scores and the formative assessment assignment scores were imported into SPSS for analysis.

To address research question 1, we used *t* tests to examine the pre- and post-tests to determine if preservice teachers' content knowledge improved. We analyzed both the total scores and the subset scores on each of the three assignments using repeated measures one-way ANOVA to determine if students engaged more productively in formative assessment over time. The formula for the repeated measures one-way ANOVA was $Y_{ij} = \pi_{0j} + e_{ij}$, where Y_{ij} is the difference between the total or subset scores on each assignment (j) for each preservice teacher (i); $\pi_0 j$ are the individual assignments per preservice teacher; and e_{ij} is the error in Y (Littell, Milliken, Stroup, Wolfinger, & Schabenberger, 2006). The dependent variable was the formative assessment assignments and the independent variable was time or, more specifically, the order in which the assignments occurred over the semester. Finally, we used multivariate ANCOVA to analyze the assignments while keeping the final exam as a fixed factor and the pretest as a covariate to determine if preservice teachers' knowledge of life science content predicted effectiveness in engaging in the FA tasks.

Qualitative Analysis

To address research questions 2 and 3, we qualitatively analyzed the interview transcripts for patterns within and across the assignments using classical content analysis (Patton, 2001). All 30 interviews were imported into qualitative analysis software (QDA Miner 4) and analyzed using pre-established codes: *Content*, *Anticipate*, *Evaluate*, *Next steps*. Two coders analyzed a 10 % sample of the data (n = 3). Inter-rater reliability between the two coders was approximately 98 % before discussion and reached 100 % after discussion; all remaining interviews were subsequently analyzed by a single coder. Following the pre-established coding, we queried the codes in which *Content* and each of the three FA components (*Anticipate*, *Evaluate*, *Next steps*) coincided (Table 2). Using these queried data, we used a pattern-matching strategy (Yin, 2009) to identify patterns within and across the three assignments and across the preservice teachers. These patterns are presented in the findings.

Table 2 Example statements for pre-established codes

Codes	Example statement without content	Example statement with content
Anticipate	"I would hope that they would be able to give me some sort of… evidence like background information or whether they had seen it somewhere else or they had read it somewhere else where they had gotten their information… I want them to be able to… explain to me why they think the way that they do or why they gave you that response, because sometimes even if it's wrong, if they have valid reasoning behind it, then it's so legitimately answered as well" (Lauren, Assignment 2)	"We had talked about seeds in class as not being, necessarily, viewed as a like a living thing. I thought that was obviously one of the misconceptions. I also wrote in here that not all students are going to understand where seeds necessarily come from. A lot of times when you see seeds, it's something that you eat, or other things. Whereas they may not understand where seeds come from, as far as flowers" (Lauren, Assignment 1)
Evaluate	"I just feel like it's very lenient, and very open-ended, so it was really hard to determine whether they got it or they didn't get it. A lot of times if they didn't include anything … I know one student left the lines completely blank and they drew something, but I had no idea what they drew. I said they didn't get it, even though I wasn't sure if they did through their drawing, but as far as what I could interpret, I couldn't interpret anything" (Sarah, Assignment 3)	"I really think anybody that said that that seed would travel by sticking on something got it, even though they may not… maybe not explain it very well… I mean it's plausible that it could travel by being thrown or it could… be picked up by the wind or something, but that's not really grasping the actual lesson, and that was what you're looking at, the physical characteristics of the seed" (Alyssa, Assignment 1)
Next steps	"…my original idea was to have them write down what they thought in their notebooks. Then, I thought that that's basically already been done, and it obviously didn't work out for the 11 who missed the idea. Going through it as a whole class and me guiding it, I think would be beneficial for those who didn't understand" (Megan, Assignment 2)	"Then I talked about bringing in protective sports equipment so they can visualize how the equipment protects them, like their bones protect them. Having a skeletal model, being able to move it around, they can see how bones move" (Taylor, Assignment 2)

Results

Content Knowledge and Formative Assessment Practices

In research question 1, we asked, "does greater content knowledge enable preservice teachers to more effectively engage in formative assessment for science?" First, analysis of the pre- and post-tests provide evidence that the preservice teachers' life subject matter knowledge for teaching increased significantly during the semester. Posttest scores were significantly higher than the pretest scores, $t(48) = 12.38$, $p = <.001$, $d = 1.49$ (see Table 3 for descriptive statistics), suggesting substantial growth in the preservice teachers' life science content knowledge.

Further, results from the repeated-measures ANOVA of the formative assessment assignments showed that the preservice teachers engaged in formative assessment

Table 3 Descriptive statistics for content exams and FA assignment scores

	M (SD)	Minimum score achieved	Maximum score achieved	Minimum score possible	Maximum score possible
Pretest (n = 49)	34.14 (4.27)	25	44	0	48
Posttest (n = 49)	40.12 (3.75)	30	47	0	48
Assignment 1 (n = 49)	53.86 (9.41)	28	72	0	80
Assignment 2 (n = 49)	57.35 (7.98)	39	72	0	80
Assignment 3 (n = 49)	54.35 (8.59)	33	69	0	80

Table 4 Statistical analysis of engagement in formative assessment over time

	F	df	p	η^2 (%)
Total assignment	5.223	2, 47	0.007*	17.7
Anticipating subset	3.694	2, 47	0.029*	7.10
Evaluating subset	8.089	2, 47	0.001*	14.4
Next step subset	2.311	2, 47	0.105	4.60

* Significant at 0.05

Table 5 Statistical analysis of content knowledge as a predictor of formative assessment engagement

	F	df	p
Assignment 1	2.391	15, 33	0.018*
Assignment 2	1.996	15, 33	0.048*
Assignment 3	1.192	15, 33	0.325

* Significant at 0.05

more productively over time (Table 4). These trends were consistent for the overall assignment scores, as well as for the FA practices of *Anticipating* and *Evaluating* students' ideas. However, we observed no statistically significant changes over time for the *Next steps* subscores on the assignments (Table 4). Therefore, our findings suggest that over the semester, the preservice teachers improved in their ability to anticipate student ideas and evaluate student work, but not in deciding what to do with that information in developing the instructional next steps.

To determine the extent to which the preservice teachers' content knowledge predicted the effectiveness of their formative assessment practices, we used multivariate ANCOVA. Overall, scores on the content knowledge assessment predicted effectiveness on the assignment score for Assignments 1 and 2, but not 3 (Table 5). This suggests that the preservice teachers' subject matter knowledge for science teaching allowed them to engage more productively in formative assessment practices for the first two assignments, but not for the third assignment.

Anticipating and Evaluating Student Ideas

In research question two, we asked, “how do preservice elementary teachers draw upon their content knowledge to anticipate and evaluate evidence of students’ thinking?”. Overall, we found that, early in the semester, preservice teachers anticipated students’ ideas and evaluated students’ responses based on their own perceived lack of life science content knowledge. They had difficulty evaluating evidence of students’ thinking due to their own uncertainty with the life science content or how to interpret student responses if they did not contain the particular words or concepts that preservice teachers expected. However, later in the semester, preservice teachers began to more specifically rely on the lesson plan, the key concept that was provided with the assignment, and/or the CTS they had completed on the topic to determine what content they should understand and evaluate in the student work. Particularly as the semester progressed, preservice teachers more commonly referred to work they had done for class, including research into topic areas or common student misconceptions. Thus, their connection of their own content knowledge came from information they had recently learned in the context of the class. This trend—preservice teachers more effectively utilizing the resources they were provided and incorporating the life science content—aligns with the ANOVA analysis that shows preservice teachers engaging more effectively in formative assessment practices over time (Table 4).

In the first assignment, almost all of the interviewed preservice teachers indicated their own lack of knowledge about the topic of seeds. For example, when asked about why she thought students might have trouble with understanding whether or not an item is a seed or if it is living, Megan said, “Mainly because those are problems I had. So I had thought that kids would also kind of think that” (Megan, Assignment 1 interview). Similarly, Sarah said, “They probably might think … well, I didn’t even know that seeds were living. Basically, they probably don’t or wouldn’t see a seed as living, or they don’t think of an idea that seeds are living” (Sarah, Assignment 1 interview). These limitations in subject matter understanding made it difficult for the preservice teachers to then determine whether or not students’ understood the target concept of the lesson. For example, when referring to evaluating students’ responses, Hannah said,

> I had no idea about the seed, if it’s on a tree, is it on a bush, does it grow from the ground, so I didn’t know if the students maybe had that background knowledge, and that’s why they were saying it fell off a tree? (Hannah, Assignment 1 interview)

Here, Hannah’s own uncertainty about the structure and function of seeds made it difficult for her to determine whether or not students understood the concept of how a seed’s properties influence its mode of dispersal. Hannah’s struggle reveals the extent to which the lack of basic content knowledge involved in the lessons made it difficult for preservice teachers to effectively anticipate or evaluate students’ ideas after the lesson.

In the second assignment, many of the preservice teachers still referred to their own lack of knowledge about target life science concepts in anticipating and evaluating students' thinking, but almost all also began to emphasize connections to content that was provided in the lesson plan or that they had encountered while completing the CTS for that topic. Megan, for example, discussed a combination of both of these by mentioning information that was provided in the lesson plan (joints are part of the skeletal system) and discussing that information in terms of her own lack of knowledge of the subject: "I put that they could get confused… that joints are… responsible for locomotion. Yet when I think of skeletal system, all I think about is bones. I don't really think about the joints being a part of that" (Megan, Assignment 2 interview). Megan's reasoning was indicative of how most of the preservice teachers began to utilize additional resources, the lesson plan in this example, to help understand the content and interpret students' thinking about the skeletal system.

By the third assignment, which involved students designing an appropriate habitat for crayfish, only a few preservice teachers still mentioned their own lack of understanding. In contrast, the majority of the preservice teachers instead focused on more sophisticated analysis of students' ideas and on connecting information from the lesson plan and the CTS. Megan, for example, referred to information she had read as a part of the CTS about habitats and students' ideas about animals in looking for particular types of misconceptions within the lesson plan, saying:

> The first one I found was that they might have misconceptions about a crayfish getting it from a pet store or finding it in the wild. I felt like students would most likely ask the teacher where she got them from… Then also the misconception that it's in the lesson plan about not defining a crayfish as an animal. (Megan, Assignment 3 interview)

Similarly, Alyssa made connections to both the lesson plan and CTS, saying:

> When I was reading through both the teacher knowledge and stuff that you should know to teach students about crayfish, I think I wrote down [in my CTS assignment] that they might not view crayfish as an animal, and I forget why … because they may not even view a human as an animal. (Alyssa, Assignment 3 interview)

In both of these examples, the preservice teachers referred to the lesson plan or reading they had done to prepare the CTS about habitats and animal life both in terms of content and research on students' ideas. In this way, the content knowledge the preservice teachers developed in class was directly applicable to their analysis of students' ideas.

However, as indicated by results from the ANCOVA analysis, the preservice teachers' content knowledge was one factor that allowed them to engage more productively in the overall formative assessment process for the first two assignments, but was not shown to be a statically significant factor in the third assignment (Table 5). The first two assignments required preservice teachers to evaluate students' ideas based on their written answers and had a clear connection between the key concept, the prompt, and students' responses. To that end, preservice teachers focused on specific criteria students' had to include to be counted as understanding. For example, in the second assignment, Taylor said, "If they were able to list the three functions [of the skeletal system]. Some of them had two, or maybe one was wrong, but for the most part, if they had the three—the protection, support and movement" (Taylor, Assignment 2 interview). Similarly, Monica said, "I put that if they put any … If they didn't have all three of [the functions of the skeletal system], they didn't understand it" (Monica, Assignment 2 interview).

However, in the third assignment, preservice teachers were asked to evaluate students' ideas based on a diagram of a crayfish habitat students drew and labeled. The preservice teachers struggled with how to evaluate students' ideas based on their drawings of a habitat and so the connection to content knowledge was less straightforward than in the second assignment where the students either wrote the correct words or did not. Sarah said, "It was a little tricky to determine whether they got it or not, because I feel when it comes to drawing, a lot of it can be from interpretation, and… we might not know what their drawing is saying" (Sarah, Assignment 3 interview). Similarly, Nicole said,

> I also think with the student work that illustrations… the water sometimes was labeled, but sometimes you didn't know if it was there or not, so I'm sure they all understood that water needed to be in the tank but I don't know if they knew that that was the basic need that [the crayfish] needed. (Nicole, Assignment 3 interview)

In both cases, the preservice teachers had specific criteria they wanted to evaluate, but were unsure how to determine whether or not students had included the criteria they wanted to see. In this third assignment, the student work did not allow the preservice teachers to evaluate the students' ideas based on the presence of particular words or phrases and so they struggled with how to interpret the ideas. This difference in format of the student work for the third assignment may have contributed to preservice teachers making less of a connection between their own content knowledge and their engagement in formative assessment.

Developing Next Instructional Steps

In research question three, we asked, "how do preservice elementary teachers draw upon their content knowledge to reason about instructional next steps?" Overall, the preservice teachers did not appear to leverage their life science subject matter knowledge to make instructional decisions about follow up instruction grounded in their analysis of students' thinking. Instead, they emphasized content-independent pedagogical considerations, relying heavily on instructional approaches represented in the lesson plans they evaluated in the assignments. For example, in the first assignment, the lesson consisted of having the students examine different types of seeds to look for differences in physical characteristics and then determine how the seeds might be dispersed. Most preservice teachers suggested next step lessons with these same procedures, such as

> I thought it was really important to bring in actual seeds, so that the kids handle and observe, and use with a magnifying glass or something. To just be

> able to look for themselves, and to see, oh, this seed has a burr, and it can stick to my clothes. (Megan, Assignment 1 interview)

Over time, more preservice teachers began using next step strategies they had learned in class as ways to address the difficulties students were having with the content. However, while the proposed strategies relied on reasonably valid pedagogy, they did not often connect to the specific content targeted in the lessons. Hannah, for example, proposed,

> I did like how they could go over all the student work as a class…and how that would help them kind of analyze each other's work to determine why did this person put this or why did this person not put something down. That way, they could kind of come up as a group with the three basic needs kind of together, rather than me just telling them. (Hannah, Assignment 3 interview)

In this example, Hannah proposed using a strategy in which the students examine anonymous student work and have a discussion about what was good about the answer and what needed improvement. The students would work as a group to analyze the examples and then would determine what a best answer would look like. While this strategy is used correctly in this example, the content connection is limited. Hannah mentioned having the students determine the three basic needs of the skeletal system, which was the key concept of the lesson, but did not connect this to the specific problems she saw with the student work and the particular problems the students had. Importantly, though, the preservice teachers were attempting to integrate these new strategies they were learning as a part of the class into the work they were doing. The attempt to utilize strategies they were still in the process of learning may be why they did not show increased scores on this subset of questions within the ANOVA analysis (Table 4).

Summary of Findings

Overall, study findings show that preservice teachers' life science content knowledge grew over the semester and they improved in their ability to engage in formative assessment practices, specifically in anticipating and evaluating students' ideas. The results suggest that the content knowledge and ability to seek out relevant information they gained during the semester, provided opportunities for them to engage more productively in the formative assessment process for the first two assignments, but not for the third. The difference in format of student work for the third assignment as compared to the first two, created difficulties for the preservice teachers in effectively evaluating students' ideas. Finally, our results suggest that some of the preservice teachers were able to begin to incorporate new next step strategies they had learned as a part of the course, but they were not yet able to effectively connect the next step strategies to the particular content they identified as lacking in students' responses.

Synthesis and Discussion

In this study, we investigated a new course designed to support preservice elementary teachers to learn to engage in the "high-leverage" instructional practice (Ball & Forzani, 2009) of formative assessment within the disciplinary domain of the life sciences. The study is grounded in prior work on elementary teachers' life science content knowledge (Haefner & Zembal-Saul, 2004; Krall et al., 2009; Rice, 2005) and the use of formative assessment in science (Bell & Cowie, 2001; Coffey et al., 2011). These two pillars are fundamental to teachers engaging students' ideas and responding to the many alternative ideas about core life science concepts that students bring to elementary science classrooms (e.g., Anderson et al., 2014; Barman et al., 2006; Grotzer & Basca, 2003). The course and research findings presented here build upon previous courses that have integrated life science content with pedagogy (i.e., Friedrichsen, 2001; Haefner et al., 2006; Weld & Funk, 2005) and contribute to a broader body of research on preservice teachers learning to engage in formative assessment for science (Buck et al., 2010; Kohler et al., 2008; Levin et al., 2009; Otero, 2006; Talanquer et al., 2013; Talanquer, Bolger, & Tomanek, 2015). Specifically, the study addresses calls for research on the discipline-specific nature of formative assessment (Coffey et al., 2011), illustrating how prospective elementary teachers interpret evidence of students' thinking about life science concepts, diagnose perceived gaps in students' understanding, and reason about student-responsive instructional next steps.

First, findings establish a relationship between life science content knowledge and formative assessment, reinforcing the discipline-specificity of at least some formative assessment practices (Coffey et al., 2011), and contributing to and extending prior work on preservice teachers' analysis of student thinking (Buck et al., 2010; Levin et al., 2009; Otero & Nathan, 2008; Talanquer et al., 2013, 2015). The positive relationship observed between the preservice teachers' content knowledge and analysis of students' ideas provides evidence for the importance of disciplinary understanding to engage effectively in formative assessment. The direct applicability of subject matter knowledge to core teaching practices is an example of the Ball et al. (2008) notion of subject matter knowledge for teaching, in this case for science. However, past work has shown teachers have limited content knowledge and may hold many of the same alternative conceptions about life science concepts as elementary and middle school students (Krall et al., 2009; Nowicki et al., 2013). The evidence presented here is encouraging in that it suggests prospective elementary teachers at the very earliest stages of their careers can develop life science content knowledge and learn to effectively translate that subject matter knowledge into elementary science classrooms, a critical component of teachers' professional learning that often poses challenges (Falk, 2011; Haefner & Zembal-Saul, 2004; Rice, 2005).

However, second, results from the study also show that preservice teachers engage in other formative assessment practices largely independent of their knowledge of science content. This reinforces findings from the field of mathematics education, which has shown math teachers tend to be better at determining student understanding than in knowing what to do with that information (Heritage et al., 2009). Here, we present evidence that extends those findings to prospective elementary teachers of science. These findings suggest that some formative assessment practices may require teachers to employ other dimensions of their expertise beyond content knowledge. We hypothesize that elements of preservice teachers' pedagogical content knowledge become crucial as teachers navigate curriculum materials, evidence of students' thinking, and instructional strategies as part of a broader process of instructional design grounded in responsive science instruction. To develop and implement follow-up instruction based on students' ideas, for example, teachers may need to employ NGSS (NGSS Lead States, 2013) to align instructional methods with grade- and discipline-specific learning performances. While some studies have explored teachers' instructional decision-making as part of formative assessment (Buck et al., 2010; Graham, 2005; Kohler et al., 2008), more work remains to identify key elements of teachers' expertise that influence this practice for science.

Finally, third, study results provide insight into how preservice elementary teachers draw upon their life science content knowledge and other resources to engage in formative assessment. The challenges the preservice teachers experienced in interpreting students' work from the third assignment suggests that varying types of student work may require varied skillsets from teachers and have important implications for the types of prompts that teachers use to elicit students' thinking. Learning to look for evidence of students' understanding in a variety of types of representations is a necessary step in teachers moving beyond "get it or don't" conceptions of formative assessment to a finer-grain analysis of students' thinking necessary to inform targeted instruction (Otero, 2006; Otero & Nathan, 2008; Talanquer et al., 2013, 2015). Further, even though we did not observe a statistically significant relationship between the preservice teachers' content knowledge and instructional next steps, we did see evidence of teachers using new, research-based instructional strategies over time. Therefore, we did see evidence of the preservice teachers beginning to implement new strategies, these strategies was just not connected to the content of the lesson or the preservice teachers' own content knowledge. This may suggest, in addition to requiring other forms of knowledge, learning to engage in effective follow-up instruction may require more time and experience in the classroom. Taken together, these findings illustrate the complexity of pedagogical reasoning underlying formative assessment practices and potential leverage points for supporting novice teachers to engage in responsive science instruction.

Implications

Elementary teacher education experiences should provide prospective elementary teachers additional opportunities to integrate disciplinary content with pedagogy. This involves, first, more experiences for them to evaluate a wide variety of types of student work and select formative assessment prompts that will align with the kind of information teachers want to gather regarding their students' ideas. Second, a greater focus needs to be placed on supporting teachers to develop the necessary skills to locate and access content support “on demand” as often necessitated by the realities of elementary science teaching. While CTS (Keeley, 2005) is an example of one such resource, there is a need for additional tools that are research-based and evolve with changing national standards. Such tools could be either tied to specific curriculum materials or developed around disciplinary topics, providing guidance for common student misconceptions, points during instruction where it might be advantageous to check for student understanding, and suggestions for how to confront gaps in student understanding through appropriate instruction. Both would provide crucial support to elementary teachers engaged in responsive science instruction. Finally, prospective teachers should be afforded opportunities to observe and experience how disciplinary content and instructional practices for science can be integrated in elementary classroom. This is critical to support their learning to elicit, interpret, and diagnose evidence of students’ thinking through “on-the-fly,” “planned-for,” or “curriculum-embedded” (Shavelson et al., 2008) approaches to formative assessment. Teacher education programs must provide prospective elementary teachers with substantial practicum experiences.

Limitations

The work described here is limited in scope in that it examined a single class of preservice elementary teachers during the first iteration of a new course. While the course and accompanying research results provide evidence that combining life science content with instructional practices can lead to gains in preservice teachers’ ability to engage with students’ science ideas, more work is needed to explore this issue. Future work should investigate how preservice teachers learn to employ formative assessment practices in the classroom, particularly instructional next steps in response to their analysis of students’ thinking. Such studies should also utilize additional measures of teacher characteristics, like PCK, that may influence their formative assessment practices. Longitudinal studies would provide invaluable insight into elementary teachers’ learning to engage in formative assessment, and responsive science instruction more generally, over longer periods of time, such as across teacher education and induction phases of their careers. Subsequent studies should also explore similarly designed integrated approaches to promoting preservice elementary teachers’ formative assessment practices within the physical and earth sciences. Such studies could ultimately be designed to attribute trends in teachers’ formative assessment practices, or changes in those practices over time, to trends in students’ science learning across a range of disciplinary contexts aligned with the *Next Generation Science Standards* (NGSS Lead States, 2013).

Conclusion

To support elementary students' science learning, teachers must craft elementary science learning environments that are responsive to students' thinking (Donovan & Bransford, 2005; NRC, 2007). Given the range of ideas, including alternative ideas, that elementary students hold about core life science concepts (e.g., Anderson et al., 2014; Barman et al., 2006; Grotzer & Basca, 2003), formative assessment is an example of a "high leverage" instructional practice (Ball & Forzani, 2009) that can help teachers engage in more responsive science instruction to support students' life science learning. However, it is not commonly implemented in elementary classrooms (Hammer et al., 2012; Morrison, 2013). Findings presented here suggest robust knowledge of the science content they teach may help teachers engage more productively in formative assessment practices and provide insight into how they leverage disciplinary knowledge to reason about students' thinking. The course (Forbes et al., in press) provides one model through which elementary teacher education can foreground formative assessment and responsive science instruction in a disciplinary context. The growing body of research to which this study contributes should continue to inform efforts in formal teacher education to afford prospective teachers opportunities to engage with and craft instruction grounded in students' thinking. Systemic efforts such as these will help realize the long-term positive impact of formative assessment practice on student outcomes in science as documented in other studies (Ruiz-Primo & Furtak, 2006; Shavelson et al., 2008).

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Appendix: Example Rubric Items for Assignment Question

Example Rubric Items for Assignment Question

Anticipating	Q1: What misconceptions or alternative ideas do you think 3rd-grade students might have about the key concept of this lesson?			
		(a) Misconceptions	(b) Connection to key concept	
	4	Response describes accurate, detailed potential misconceptions	Response describes misconceptions that are accurately linked to the key concept	
	3	Response describes mostly accurate potential misconceptions	Response describes misconceptions with some connection to the key concept	
	2	Response describes only partially correct or vague potential misconceptions	Response includes misconceptions that are only vaguely linked to the key concept	
	1	Response describes inaccurate misconceptions	Response describes misconceptions that are not linked to the key concept	
	0	No response	No response	
	Q2: How effectively do you think the question students were asked elicited their understanding of the key concept?			
		(a) Rationale	(b) Connection to student understanding	(c) Link to key concept
	4	Response includes accurate, detailed rationale for the effectiveness/ineffectiveness of the question.	Response includes an accurate description of how the question elicited student understanding	Response is accurately linked to the key concept
	3	Response includes general rationale for the effectiveness/ineffectiveness of	Response includes a mostly, but not completely, accurate	Response has some connection to the key

	the question.	description of how the question elicited student understanding	concept
2	Response includes vague rationale for the effectiveness/ineffectiveness of the question	Response includes a vague or mostly inaccurate description of how the question elicited student understanding	Response is only vaguely linked to the key concept
1	Response does not provide rationale or indicates the respondent does not understand why the question is effective/ineffective	Response does not address or inaccurately describes how the question elicited student understanding	Response is not linked to the key concept
0	No response	No response	No response
Q3: Why do you think the question was or was not effective?			
	(a) Effectiveness	(b) Connection to key concept	
4	Response includes accurate, detailed rationale for the effectiveness/ineffectiveness of the question	Response is accurately linked to the key concept	
3	Response includes general rationale for the effectiveness/ineffectiveness of the question	Response has connection to the key concept but may not fully articulate or be completely correct	
2	Response includes vague rationale for the effectiveness/ineffectiveness of the question	Response is only vaguely correctly linked to the key concept or has more that is incorrect than correct	
1	Response does not provide rationale or indicates the respondent does not understand why the question is	Response is not linked to the key concept or is completely incorrect	

		effective/ineffective	
	0	No response	No response
	Q4: Given the question the students were asked, what are you looking for in students' responses as evidence of their understanding of the key concept?		
		(a) Specificity	(b) Connection to key concept
	4	Response describes specific evidence of understanding in students' responses	Response is accurately linked to the key concept
	3	Response describes general evidence of understanding in students' responses	Response has connection to the key concept but may not fully articulate or be completely correct
	2	Response describes vague evidence of understanding in students' responses	Response is only vaguely correctly linked to the key concept or has more that is incorrect than correct
	1	Response does not provide evidence of understanding in students' responses	Response is not linked to the key concept or is completely incorrect
	0	No response	No response
Evaluating	Q5: Overall, what patterns did you notice in the student work you reviewed?		
		(a) Accuracy of trends	(b) Connection to key concept
	4	Response describes accurate, detailed trends in student understanding	Response is accurately linked to the key concept
	3	Response describes trends in student understanding, but may be partially incomplete or not completely correct	Response is mostly accurately linked to the key concept
	2	Response only vaguely describes trends in students	Response is minimally linked to

	understanding or is more incorrect than correct	the key concept
1	Response does not answer the question or is completely incorrect in describing trends in student understanding	Response is not linked to the key concept or indicates the respondent does not understand the key concept
0	No response	No response
Q6: For the students who got it, what was your evidence that they understood the key concept? Describe this evidence as thoroughly as possible. Provide specific examples from the student work.		
	(a) Connection to student understanding	(b) Connection to key concept
4	Response includes an accurate description of students' understanding	Response is accurately linked to the key concept
3	Response includes a mostly accurate description of students' understanding	Response is mostly accurately linked to the key concept
2	Response includes a mostly inaccurate description of students' understanding	Response is minimally linked to the key concept
1	Response does not address or inaccurately describes students' understanding	Response is not linked to the key concept or indicates the respondent does not understand the key concept
0	No response	No response
Q7: For the students who showed partial or no understanding, what were some consistent challenges and/or misconceptions that you saw in their work? Describe these as thoroughly as possible. Provide specific examples from the student work.		
	(a) Accuracy of students' challenges/misconceptions	(b) Connection to key concept
4	Response includes an accurate description of students'	Response is accurately linked to

		challenges or misconceptions	the key concept	
	3	Response includes a mostly accurate description of students' challenges or misconceptions	Response is mostly accurately linked to the key concept	
	2	Response includes a mostly inaccurate description of students' challenges or misconceptions	Response is minimally linked to the key concept	
	1	Response does not address or inaccurately describes students' challenges or misconceptions	Response is not linked to the key concept or indicates the respondent does not understand the key concept	
	0	No response	No response	
Next steps	Q8: Based on the student work you reviewed, outline a lesson you could use as a next step to address misconceptions or gaps in understanding that you observed in the students' work.			
		(a) Detail/specificity of the lesson	(b) Connection to key concept	(c) Connection to student understanding
	4	Response includes a detailed lesson	Response is accurately linked to the key concept	Lesson strongly and accurately addresses previously described student understanding
	3	Response includes a general lesson	Response is mostly accurately linked to the key concept	Lesson generally links to previously described student understanding
	2	Response includes a vague lesson	Response is minimally linked to the key concept	Lesson loosely links to previously described student

			understanding
1	Response provides general ideas but not an actual lesson	Response is not linked to the key concept or indicates the respondent does not understand the key concept	Lesson is not appropriately linked to the previously described student understanding
0	No response	No response	No response

Q9: Describe why you designed your lesson the way that you did. How do you think your follow-up lesson will enhance students' understanding of the key concept?		
	(a) Rationale	(b) Student understanding
4	Response provides accurate, detailed rationale for the proposed lesson	Response provides an accurate, detailed connection to student understanding as previously identified
3	Response provides general rationale for the lesson	Response provides general connection to student understanding as previously identified
2	Response provides minimal rationale for the lesson	Response provides minimal connection to student understanding as previously identified
1	Response does not provide rationale for the lesson or indicates the respondent does not understand the purpose of the proposed lesson	Response does not connect to student understanding as previously identified or indicates the respondent does not understand how the proposed lesson relates to student understanding
0	No response	No response

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