Content Knowledge and Formative Assessment Integration in a Life Sciences Methods Course for Preservice Teachers

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Abstract

Preservice elementary teachers should learn essential science concepts, how to apply those concepts to practice in elementary science learning environments, and how to effectively connect students' ideas to appropriate instructional strategies. In order to effectively engage students in scientific practices and connect instruction to students' ideas, teachers should learn to engage in high-leverage instructional practices, such as formative assessment. 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 an innovative course for elementary preservice teachers built upon two pillars—life science disciplinary content and formative assessment. Students learned biological science content and how to connect disciplinary ideas to essential concepts in the K-12 science standards. The focus on formative assessment provided opportunities for preservice teachers to utilize content knowledge to identify and respond to students' ideas. An embedded mixed methods study was used to evaluate the effect of this intervention on preservice teachers' content knowledge and ability to engage in formative assessment practices for science. Findings showed that increased content knowledge over the semester helped preservice teachers engage more productively in anticipating and evaluating student ideas, but not in choosing next instructional steps based on those ideas.

Descriptors: preservice teacher education, formative assessment, life science

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Preservice elementary teachers often have limited science subject matter knowledge and the disciplinary content they encounter in teacher education programs is typically not easily translated to use in elementary science learning environments (Rice, 2005; Haefner & Zembal-Saul, 2004). Prospective science teachers should learn essential science concepts, how to identify those concepts within national and local standards, how to engage students in scientific practices, and how to connect students' ideas about science to appropriate instructional strategies, such as formative assessment, in order to respond to their students' ideas.

Formative assessment is a teaching and learning practice grounded in contemporary perspectives on learning that places students' existing ideas as the focus in shaping instruction. Effective science learning environments utilize these preexisting ideas and provide opportunities for students to recognize, expand, and refine their understanding of the world (NRC, 2007). Formative assessment strategies are an important part of teachers creating student-centered learning environments in their classrooms by genuinely engaging with student ideas, taking individual student progress into account, and crafting responsive instruction (Bell & Cowie, 2001; Coffey, Hammer, Levin & Grant, 2011).

The ability of teachers to foster learning environments grounded in students' thinking is dependent on teachers' understanding of how learning develops, their knowledge of disciplinary content, and on their pedagogical content knowledge (Heritage, Kim, Vendlinski, & Herman, 2009). 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 (Coffey et al., 2011). Research suggests that teachers are typically better at determining what their students understand than deciding what to do next with that information (Heritage et al., 2009) and need support to incorporate content knowledge into practice in order to engage in formative assessment effectively (Coffey et al., 2011). Therefore, all teachers, including prospective teachers, need opportunities to integrate content knowledge with effective elementary science pedagogy. However, with few exceptions (Friedrichsen, 2001; Haefner, Friedrichsen and Zembal-Saul, 2006; Weld & Funk, 2006), courses that integrate these two components have not been implemented and studied. In particular, more research is needed to determine the effect on preservice teachers' engagement in instructional practices when teacher education includes integration of content knowledge with instructional strategies that forefront students' ideas.

To address these gaps in the research literature, we conducted research around the implementation of a new course for preservice elementary teachers built upon two pillars—life science disciplinary content and formative assessment. This combined focus allowed preservice teachers to learn to use content knowledge to identify trends in elementary student understanding and propose next instructional steps. To study the effect of the 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?

Background and Theoretical Framework

Elementary students bring preexisting ideas about the natural world that they have constructed from experiences in their daily lives with them when they enter science classes (Donovan & Bransford, 2005). These ideas may not be scientifically accurate and may need to be expanded or refined. To that end, past research has shown that elementary students hold a variety of alternative ideas about core life science concepts (Anderson, Ellis, & Jones, 2014; Barman, Stein, McNair, & Barman, 2006; Grotzer & Basca, 2003). Science teachers must elicit and utilize students' preexisting ideas in order to give students the opportunity to recognize, expand, and refine their understanding (NRC, 2007). However, most teachers tend to keep their focus on other aspects of classroom context, such as curriculum or classroom routines, and do not consider students' ideas (Levin, Hammer, & Coffey, 2009). Otero and Nathan (2008) have shown that the views preservice teachers have of students' prior science knowledge impacts both their assessment and teaching practices. Teachers' continual improvement of their practice is dependent, in part, on consideration of student thinking and the conditions necessary for students to learn science (Levin, et al., 2009). In order to create science learning environments that are responsive to students' thinking, teachers must understand how learning develops as well as disciplinary content and pedagogical content knowledge (Heritage et al., 2009); taken together, these constitute subject matter knowledge for teaching (Ball, Thames, & Phelps, 2009). This type of responsive instruction can help students "construct understanding of scientific concepts, reason scientifically, appreciate the nature of science, and engage in scientific practices" (Levin et al., 2009, p. 152).

Research on Preservice Teachers and Responsive Science Instruction

Past work has shown that preservice teachers consider preassessment to be disconnected from, or have no relationship to, the notion of student conceptual development (Otero, 2006). Even when preservice teachers do understand the importance of eliciting student's particular ideas, they often do not understand the importance of creating instruction that responds to those students' ideas and needs nor in providing the type of feedback that allows students to advance their learning (Buck, Trauth-Nare, & Kaftan, 2010). As a result, preservice teachers also need to learn how they can integrate theory of how students learn with specific teaching practices that will help students' conceptual development (Otero, 2006). Specifically, teachers need to learn how to recognize and use students' ideas to inform formative assessment practices that will help connect students' prior knowledge to academic objectives (Otero, 2006). Preservice teachers tend to have limited views of what constitutes students' prior knowledge and privilege academic or experience-based concepts for use with formative assessment (Otero & Nathan, 2008). To that end, teachers may also need opportunities to consider the particular aspects of student ideas that require action in order to both effectively understand and enact appropriate formative assessment (Otero & Nathan, 2008).

Past research has shown that preservice teachers often consider students' knowledge in terms of "get it or don't" conceptions (Otero, 2006). This conception often leads to preservice teachers looking for particular clues from students such as whether or not they stated key vocabulary words or if they could discuss particular background knowledge they had learned in a prior context (Otero, 2006). This perceived dichotomy of "get it or don't" has consequences for how preservice teachers conceive of responding to students' ideas. If students' "get" the concept in preassessment, preservice teachers tend to then choose not to teach about the concept at all; whereas, if students "don't get" the concept, preservice teachers proceed with the lesson as originally planned, even if an alteration might be useful to respond to students' particular ideas (Otero, 2006). It is important for preservice teachers to learn how to enact formative assessment in ways that go beyond simply deciding whether students "get it or don't" (Otero, 2006). This requires a focus within teacher education on the way and the context in which students learn and attention to student thinking (Levin et al., 2009).

Formative Assessment

An important way to elicit and respond to students' ideas is through the high-leverage instructional practices of formative assessment (Ball & Forzani, 2009). The practice of formative assessment is grounded in contemporary learning theory and places emphasis on students' ideas directing instruction. Formative assessment strategies allow teachers to engage with individual students' ideas and to craft responsive instruction (Bell & Cowie, 2001; Coffey et al., 2011). The practice of formative assessment involves (a) anticipating and eliciting students' ideas, (b) evaluating students' ideas, and (c) crafting next steps in instruction that connect to students' ideas and are designed to support students' learning.

Unfortunately, the use of formative assessment within elementary science classrooms is not widespread (Hammer, Goldberg, & Fargason, 2012; Morrison, 2013; Otero & Nathan, 2008). Elementary teachers have been shown to lack sufficient knowledge of formative assessment or enough content knowledge to effectively implement the practice (Coffey et al., 2011). When they do implement formative assessment, teachers tend to be better at evaluating student understanding than at selecting follow up instructional strategies that are responsive to that understanding (Heritage et al., 2009). Past work has shown student teachers rely on limited formative assessment strategies and are often unable to provide sufficient rationale for the strategies they choose to implement and need opportunities to engage and reflect on these types of learning strategies during their teacher preparation programs (Kohler, 2008). To that point, Graham (2005) showed that preservice teachers were able to expand their knowledge of classroom assessment by engaging in professional dialogues while in a teacher preparation program. Further, Buck et al. (2010) showed including formative assessment within a science methods course led to increased understanding of some aspects of formative assessment, but preservice teachers still needed more knowledge of how formative assessment was used to guide instructional plans.

Subject Matter Knowledge for Responsive Science Teaching

Though disciplinary content and pedagogical content knowledge are necessary components for teachers to effectively create science learning environments, past research has shown that elementary teachers may not possess sufficient science content knowledge to engage in the practice of formative assessment effectively (Heritage et al., 2009; Coffey et al., 2011). Teachers have been shown to have some of the same alternative conceptions as elementary and middle school students and so are often not sufficiently prepared to teach science to those students (Krall, Lott, & Wymer, 2009). However, research has shown that teachers can learn and accurately present content to their students when they are provided with high quality curricula and professional development (Nowicki, Sullivan-Watts, Shim, Young, & Pockalny, 2010).

Prospective science teachers need support to learn essential science concepts as well as how to translate those science concepts into effective elementary science learning environments to build pedagogical content knowledge (PCK) and implement effective elementary science pedagogy, including formative assessment (Coffey et al., 2011). Unfortunately, preservice elementary teachers often have limited science subject matter knowledge and the science they encounter as undergraduate students is not easily translated to the elementary science classroom

(Rice, 2005; Haefner & Zembal-Saul, 2004). As a result, preservice teachers need to learn science content but also how that content aligns with national and local standards, how to engage students in scientific practices, and how to implement appropriate instructional strategies in order to connect students' ideas to scientifically accurate concepts. Teachers can use formative assessment to increase their knowledge of student understanding and build PCK. For example, teachers' interpretation of student responses can help increase their knowledge of student understanding, articulation of goals can help increase their knowledge of the curriculum, and use of assessment tasks can increase their knowledge of assessment (Falk, 2011).

Study Design and Methods

We used an embedded mixed methods design (Caracelli & Greene, 1997) in which quantitative and qualitative methods were embedded within the larger course development process (Cresswell & Plano Clark, 2011).

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 undergraduate students enrolled in a three-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 math, and 42 indicated language arts/reading.

The New Course

The innovative course we developed integrated life science content with instructional strategies appropriate for elementary science classrooms. The purpose of the course was to provide undergraduate elementary preservice teachers with the necessary tools to develop a robust understanding of the essential concepts in the biological sciences, opportunities to implement elementary science curriculum materials to engage in effective instruction about biological concepts, and resources and opportunities to connect the relevant pieces of adult content knowledge 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 and the combination of content and formative assessment allowed preservice teachers to use relevant content knowledge as they evaluated elementary student understanding and selected next instructional steps to address trends in students' ideas.

The course consisted of a central lecture that focused on life science content and weekly, small-group methods labs designed to help students connect life science content to teaching practices, including formative assessment strategies. Guiding questions for the course included (a) What are the essential concepts in the biological sciences that constitute the elementary science curriculum?, (b) What has past research shown about elementary students' ideas and learning in the biological sciences?, (c) What are the characteristics of effective elementary science curriculum materials designed to promote students' learning of essential concepts in the biological sciences?, and (d) What are the crucial instructional strategies that promote students' learning of essential concepts in the biological sciences?.

The life science content was selected to align with Curriculum Topic Study (CTS; Keeley, 2005). CTS is a set of tools and resources that allow teachers to focus on curriculum, instruction, assessment, and teacher content knowledge around a particular science topic (Keeley, 2005). CTS templates provide teachers with direction to resources that will allow them to incorporate content knowledge with science standards and research on student ideas. These templates are often used by inservice teachers for planning lessons and professional development (Keeley, 2005). 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 of the semester. The CTS guide topic for each week aligned with the life science content focus of the lecture and the methods lab integrated pedagogical implications for that topic.

Data Collection

The data for this study consisted of course-related artifacts and student interviews. Each preservice teacher in the course (N=49) completed a multiple-choice test of their life science content knowledge at the beginning and end of the semester. 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 were chosen to align with the CTS topics covered in the course.

Preservice teachers also completed three formative assessment assignments that aligned with relevant CTS content topics. In these assignments, they were required to engage in a series of tasks and questions that elicited their pedagogical reasoning of elementary science lessons and student work (Table 1). Preservice teachers were first asked to answer questions related to their content knowledge about the particular assignment topic. They then reviewed a lesson plan and were asked to anticipate ideas students might have about the topics and identify challenges students might have with understanding the key concept of the lesson. Next, preservice teachers examined actual elementary student work associated with the lesson and evaluated students' responses to identify trends in student thinking. Finally, they were asked to propose next instructional steps to address the gaps they identified in 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.

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

Table 1

Formative Assessment Assignment Descriptions

Assignment	Content	Key concept	Question on student worksheet
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?
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?
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 the crayfish have that you could not draw?

Data Analysis

Quantitative Analysis. The pre- and posttests were scored and the final score was used for subsequent statistical analysis. The three formative assessment assignments were scored using a rubric we created. The rubric aligned with each of the questions on the assignment and examined how well preservice teachers (a) understood content knowledge, (b) anticipated student ideas, (c) evaluated student responses, and (d) proposed next instructional steps. Within each of these categories, the rubric further analyzed 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 from 0-4 where 4 indicated a response that included detailed rationale or an accurate link to a key concept, 3 indicated partial accuracy or detail, 2 indicated partial inaccuracy or a lack of sufficient detail, 1 indicated complete inaccuracy or a response that did not address the question, and 0 indicated no response at all. See Table 2 for an example of rubric items associated with an assignment question.

The rubric went through multiple rounds of revision until two scorers were able to obtain consistent scores. Two scorers analyzed a 10% sample of the assignments. Inter-rater reliability between the two scorers was 72% before discussion and reached 100% following discussion; all remaining assignments were scored by a single scorer. We calculated a total score for each assignment as well as subscores for each major component: *Content* knowledge, *Anticipating* student ideas, *Evaluating* trends in student understanding, and choosing *Next steps* in instruction. The pre- and posttest scores and the formative assessment assignment scores were imported into SPSS for further analysis.

Table 2

Example rubric items for assignment question

Q: 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

To address research question 1, we used *t*-tests to examine the pre- and posttests and assignments to determine if students' content knowledge improved and if students scored significantly differently on the total assignments or on any of the subsets of questions. 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 $Y_{ij} = \pi_{0\mathrm{j}} + e_{ij}$, 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 et al., 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 predicts 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. 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 (Appendix A). Using these queried data, we identified emergent themes that were compared using 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.

Results

Content Knowledge and Formative Assessment Practices

In research question 1, we asked if greater content knowledge enabled preservice teachers to more effectively engage in formative assessment for science. The posttest scores were significantly higher than the pretest scores ($t(48) = 12.38$, $p = 1.51\text{E-}16$, Cohen's $d = 1.49$; see

Table 4 for descriptive statistics), suggesting the preservice teachers' knowledge of life science content grew over the semester.

Table 4

Descriptive Statistics for Content Exams and FA Assignment Scores

	M(SD)	Min score achieved	Max score achieved	Min score possible	Max 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

Further, the repeated-measures ANOVA shows that the preservice teachers engaged in formative assessment more productively over time for the total assignment scores (Table 5). This was also the case for the FA practices of *Anticipating* and *Evaluating* students' ideas, but not for the *Next steps* subsets on the assignments (Table 5). Therefore, our findings suggest that the preservice teachers significantly 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 next instructional steps.

Table 5

Statistical Analysis of Engagement in Formative Assessment Over Time

	F	df	*p*
Total assignment	5.223	2, 47	0.007*
Anticipating subset	3.694	2, 47	0.029*
Evaluating subset	8.089	2, 47	0.001*
Next step subset	2.311	2, 47	0.105

*Significant at 0.05

To determine the extent to which the preservice teachers' content knowledge predicted their effectiveness of engagement with formative assessment, we used multivariate ANCOVA. We found that the content score on the final exam predicted effectiveness on the assignment score for Assignments 1 and 2 but not for Assignment 3 (Table 6). This suggests that content knowledge allowed students to engage more productively in the overall formative assessment process for the first two assignments, but not for the third assignment which may be due to the difference in the nature of the student work the preservice teachers had to evaluate. These differences will be discussed further in the following section.

Table 6

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

Anticipating and Evaluating Student Ideas

In research question two, we asked how preservice elementary teachers drew upon their content knowledge to anticipate and evaluate evidence of students' thinking.

Anticipating. In all three assignments, we found preservice teachers anticipated concepts students might struggle with based on their own misunderstandings or recognized lack of knowledge about the topic. For example, in Assignment 1, Sarah said, "They probably might think … well, I didn't even know that seeds were living" (Sarah, Assignment 1 interview). Referring to Assignment 2, Megan said, "I put that a question could arise that, why doesn't cartilage such as in the nose and the ears not turn into bone? I wouldn't really know how to answer that for them" (Megan, Assignment 2 Interview). And on Assignment 3, Lauren said, "I had said previously, my background knowledge of crayfish wasn't very extensive so I think a lot of students hadn't seen an aquatic animal unless they have it in their home or been to an aquarium, things like that” (Lauren, Assignment 3 interview). In all three of these examples, the preservice teachers recognized their own lack of knowledge about the particular topic and inferred that elementary students would likely struggle with the same ideas. While the preservice teachers may be correct in their anticipation of student ideas, this reveals the extent to which the preservice teachers lack some of the basic content knowledge they might need to effectively teach the lessons.

However, by the third assignment, many of the preservice teachers began more specifically discussing students’ prior conceptions and how they might influence students’ understanding and responses. For example, Hannah said, “I don't know if students would have prior knowledge about crayfish and aquatic organisms, rather, because usually you focus on land animals when you're talking about animals” (Hannah, Assignment 3 interview). Lauren said, “I thought because of the crayfish's distinct characteristics, students might have a hard time conceiving it as an animal because their schema for animals may be not that extensive” (Lauren, Assignment 3 interview). While some preservice teachers still discussed their own misunderstandings in terms of what they thought students would understand, others were beginning to include more sophisticated analysis of students’ ideas, and to connect them to ways in which students learn, when they anticipated student understanding.

Evaluating. In all three assignments, preservice teachers had difficulty evaluating students’ ideas due to their own uncertainty with the content or how to interpret student answers if they did contain the particular words or concepts that preservice teachers expected. Hannah said,

> And I remember saying that, like 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? Because I didn't know, if that's where it grows, is on a tree. (Hannah, Assignment 1 interview)

Here, Hannah's own uncertainty about the content made it difficult for her to determine whether or not students' understood the concept. In a second example, Nicole described her criteria for determining student understanding as "…unless I was 100% sure that they understood it by having all three of the concepts, or the key concepts, or the three basic needs written down, then I said they still did not get it fully" (Nicole, Assignment 3). Here, Nicole understood the three basic requirements of a crayfish habitat, but only counted students as understanding if their answer aligned exactly with her understanding of the concept.

Differences in the format of the three assignments may have led to differences in how the preservice teachers were able to consider and evaluate students' understanding. The first two assignments required preservice teachers to evaluate students' ideas based on their written answers. The second assignment was the most straightforward of all three in terms of connection between the key concept and the responses student's provided on the student work. To that end, preservice teachers focused on specific criteria students' had to include to be counted as understanding. For example, Taylor said, "If they were able to list the three functions. 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 them, they didn't understand it" (Monica, Assignment 2 interview).

However, in the third assignment, preservice teachers had to evaluate students' ideas based on a picture students' drew of a crayfish habitat. The preservice teachers struggled with how to evaluate students' ideas based on their drawings 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 if you don't talk to the student about what their drawing includes, or what they're trying to say, 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, like we said, 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 they needed. (Nicole, Assignment 3 interview)

In both cases, the preservice teachers had specific criteria they wanted to evaluate, but struggled with how to determine whether or not students really had 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.

Reliance on curricular materials. In all three assignments, preservice teachers relied heavily on the lesson plan or the key concept that was provided with the assignment to determine what content they should understand and evaluate in the student work. Due to the nature of the second assignment, preservice teachers tended to rely specifically on the key concept and its direct relationship to student answers (as described above). In contrast, the answers for the first and third assignments were less connected to the specific language of the key concepts. As a result, preservice teachers relied more heavily on information provided in the lesson plan or from content they had learned in the class or in the process of completing the CTS. Particularly as the semester progressed, preservice teachers more commonly referred to work they had done for class, including research into particular 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. In Assignment 3, Alyssa said, “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 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). Similarly, Miranda said, “I talked about how a lot of the misconceptions from the CTS are you start with ... or one of the good things is you look at what the students know and what they can find in their environment” (Miranda, Assignment 3 interview). In both of these examples, the preservice teachers referred to the reading they had done to prepare the CTS for that topic both in terms of content and research on students’ ideas. In this way, the content knowledge the preservice teachers learned in class were directly applied to their analysis of students’ ideas.

Developing Next Instructional Steps

In research question three, we asked how preservice elementary teachers drew upon their content knowledge to reason about instructional next steps. In the first assignment, preservice teachers proposed follow-up instruction that consisted of reteaching the original lesson with little modification. 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. Or this seed is really light, and it could travel by wind. (Megan, Assignment 1 interview)

Any new ideas they presented involved only slight changes from the original lesson, such as using different seeds. For example, Lauren said, “Maybe use a seed that they're more familiar with, not necessarily one that we've worked with” (Lauren, Assignment 1 interview).

By the second assignment, preservice teachers proposed new ideas that were different from the original lesson, but struggled to connect them to the specific trends and misconceptions they saw in the student work. In Assignment 2, for example, Sarah tried to connect a concept the students struggled with (the function of the skeletal system in protecting internal organs) with a concept they understood (the function of the skeletal system in moving the body):

> I'd try to do something with motion because at jump rope, they really got it for that one. The movement. A lot of them got the movement part, and I thought it's because they did something that was fun, and it was memorable, and it was right there. For the protection, I'd try to do other movement activities and such so that they would also as well get what the other functions were. (Sarah, Assignment 2 interview)

Similarly, Lauren said, “The follow-up lesson, I said I want to minimize the misunderstanding of the term function as well as shed light on other students or whether they were actually struggling with that phrasing or it was just a mastery of the concept” (Lauren, Assignment 2 interview). Although both proposed a next step that was responsive to the students’ understanding, they did not articulate how they would connect the protection function to movement activities or how that would enhance students' understanding of the key concept.

By the third assignment, preservice teachers focused more on connecting to the issues they saw in the student work; specifically, the elementary students were not thinking of a natural habitat when they answered questions about a crayfish habitat. In Assignment 3 Megan proposed,

> My follow-up lesson would be showing them a video clip of a crayfish living in the real bio-habitat. First I would explain the basic needs of the crayfish in the classroom habitat and then we would watch the video. I said we could pause it when a student points out one of the basic needs found. Then we could find similarities and differences between those, so the crayfish living in our classroom might use pots as their shelter, but the crayfish in the wild don't have that, so they would use rocks or find something else. (Megan, Assignment 3 interview)

Though she still lacked some rationale for how these ideas would enhance student understanding, Megan clearly identified what steps she would take and connected the ideas to the problems that she identified in the student work.

Use of newly learned strategies. By the third lesson, the 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, the proposed strategies were used generically and did not necessarily contain specific content from the lesson. Hannah proposed,

> I did 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, 'The three basic are.' If they're working as a group and reviewing student work, they can kind of think about it all together. (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, 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. This was common when the new strategies were implemented in that the preservice teachers connected them superficially to the topic of the lesson or the student work, but did not discuss how the particular strategy specifically would help enhance student understanding. 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.

Summary of Findings

This study focused on the effect of implementation of an integrated course for preservice elementary teachers that was built upon the two pillars of life science content and formative assessment. The research focused on the extent to which content knowledge enabled preservice teachers to more effectively engage in formative assessment for science as well as how preservice elementary teachers drew upon content knowledge to anticipate and evaluate students' ideas and propose next instructional steps based on those ideas. We found 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 content knowledge they gained during the semester allowed them to engage more productively in the formative assessment process for the first two assignments, but not for the third. In the qualitative analysis, we found that preservice teachers anticipated student understanding based on their own misunderstandings or lack of content knowledge and they had difficulty with evaluating students' ideas due to their lack of content knowledge or the lack of alignment with the students' responses to the preservice teachers' content knowledge. The content the preservice teachers discussed often came from the lesson plan and key concept or from information they learned in the class and by completing the CTS. Finally, the preservice teachers were able to incorporate more of a connection to students' particular ideas into the next instructional steps they proposed as they progressed through the semester and were able to begin to incorporate new strategies learned as a part of the course.

Synthesis and Discussion

In this study, we investigated an innovative approach to addressing the need for engaging preservice elementary teachers in integrating science content knowledge with effective elementary science instruction. The study is grounded in, and informs research on, preservice elementary teachers' disciplinary knowledge of science (Haefner & Zembal-Saul, 2004; Rice, 2005) and high-leverage formative assessment practices (Ball & Forzani, 2009; 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 (Anderson, Ellis, & Jones, 2014; Barman, Stein, McNair,

& Barman, 2006; Grotzer & Basca, 2003). Though previous courses have integrated content with pedagogy (i.e., Friedrichsen, 2001; Haefner, Friedrichsen, Zembal-Saul, 2006; Weld & Funk, 2005), the innovative new course we designed builds upon these efforts to emphasize life science content, responsive science instruction, elementary standards, and research on students' ideas to support K-5 student learning in the life sciences. Findings from this study provide insight into how preservice elementary teachers integrate content knowledge and formative assessment practices and inform the design of future science teacher education courses.

First, results show that preservice teachers were able to develop more content knowledge over the semester. Though some of this content was delivered through lectures, much of it came from the preservice teachers engaging in CTS and connecting relevant adult content knowledge to students' ideas and elementary standards. This combination of content knowledge and pedagogical content knowledge is what Ball et al. (2008) refer to as subject matter knowledge for teaching. Thus, not only did preservice teachers learn life science content, they also learned about the process and resources they will need as practicing teachers to seek out and learn relevant content as they begin to engage with new curricula and teach a wider variety of science lessons.

Second, increased content knowledge allowed them to engage more productively in formative assessment practices, particularly in effectively anticipating and evaluating student ideas. Though past work has shown that elementary teachers may not possess sufficient content knowledge to effectively implement formative assessment (Coffey et al, 2011), the findings from this study indicate increasing content knowledge can have measurable effects on improvements to formative assessment practices. The preservice teachers often anticipated and evaluated student's ideas based on their own understanding, or lack of understanding, of the content. This aligns with our statistical analysis that showed preservice teachers with more robust content knowledge were able to more effectively anticipate and evaluate student's ideas. However, by later assignments, they were able to incorporate life science content and research into students' ideas they had learned as a part of the course. This shows that the course helped the preservice teachers understand and engage in important aspects of student learning and teacher practice, in particular, that students' come to classrooms with preexisting ideas that must be elicited in order to expand and refine understanding and that content knowledge must be integrated into teaching practices (Coffey et al., 2011; Donovan & Bransford, 2005; NRC, 2007).

The preservice teachers struggled to evaluate students' ideas on the third assignment more than on the previous two. This was likely due, in part, to the difference in the nature of the student work they evaluated. The students' ideas in the third assignment were in the form of drawings, rather than written text. The preservice teachers were not able to easily see the particular words that would have indicated students' understanding and, therefore, struggled with interpreting those ideas. This has important implications for the types of prompts that teachers choose to give to students and how well they align with the ideas they are trying to evaluate in the student work. Learning to look for understanding beyond particular key vocabulary words in a necessary step in preservice teachers moving beyond "get it or don't" conceptions of formative assessment (Otero, 2006).

Third, results indicate that the increased content knowledge did not help students propose next instructional steps, at least during the semester. This aligns with previous research that 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 have extended those findings to prospective science teachers and have identified some ways in which they differentially engage in these formative assessment steps. Though the improvement in the preservice teachers' engagement in proposing next instructional steps was not statistically significant, they did make noticeable qualitative gains in how they incorporated students' ideas into the next instructional steps they proposed. Although the next steps proposed for the first assignment typically involved repetition of the original lesson, by the third assignment the preservice teachers were more specifically connecting the lesson they proposed to the students' ideas they had evaluated. In order to create instruction that is responsive to students' ideas, teachers must first give attention to those ideas and student thinking (Levin et al., 2009). Thus, analyzing student work in this way may provide the preservice teachers with the types of opportunities that will allow them to consider the particular aspects of student ideas that require action so that they can create effective formative assessment in their classrooms (Otero & Nathan, 2008).

Finally, by the third assignment, the preservice teachers also increased their use of newly-learned strategies, but often did not connect those strategies to the content with which the students had difficulty. Though they still relied on limited formative assessment strategies and did not provide sufficient rationale, the preservice teachers' initial attempts at implementing these ideas shows that the course provided them with needed opportunities to engage and reflect on learning strategies (Kohler, 2008). It is noteworthy that they were still learning to utilize these strategies which suggests that, with additional practice and support, the preservice teachers may be able to more effectively integrate the strategies with their own content knowledge and with students' ideas.

Implications and Conclusion

Findings from this study have important implications for the preparation of future elementary science teachers. Previous work has shown that integrating formative assessment into a methods course can lead to increased understanding of formative assessment among preservice teachers (Buck et al., 2010). Further work has focused on how preservice teachers can expand their formative assessment knowledge and build PCK through engagement in professional dialogues and engagement with assessment tasks (Graham, 2005; Falk, 2011). Here we show that combining content knowledge with instructional methods can lead to gains in how preservice teachers engage in high-leverage instructional practices (Ball & Forzani, 2009). By integrating these pieces, prospective teachers may be more prepared to create the kind of effective science learning environments that utilize student ideas to increase their understanding of the natural world (NRC, 2007). The findings from this study support past assertions that preservice teacher education should include attention to students' learning and thinking as well as opportunities to engage in learning strategies, such as formative assessment that engage students' ideas (Kohler, 2008; Levin et al., 2009). Though the use of formative assessment strategies in elementary science classrooms is not currently widespread (Hammer et al., 2012; Morrison, 2013; Otero & Nathan, 2008), a focus on formative assessment and the content knowledge required to implement the practice within teacher education programs is necessary to ensure teachers can effectively engage in and implement these practices.

The work described here is limited in scope in that it examined a single class of preservice teachers in just a single semester of engagement. The study took place during the first implementation of a newly-designed course and, as such, we have identified improvements to include in subsequent iterations. Additional integration of content and teaching practices is desirable as are changes to course content to further align with the Next Generation Science Standards (NGSS Lead States, 2013). In particular, preservice teachers should be exposed to a variety of opportunities and resources to learn how to access the content knowledge they will need to teach a wide variety of science lessons. Further, they should have more opportunities to evaluate diverse types of student work and ideas through formative assessment activities and practices. Finally, a practicum experience in which preservice teachers engage in elementary science classrooms is a necessary component to allow preservice teachers to put these practices into context.

Past work has shown teachers have limited content knowledge and the same alternative conceptions as elementary and middle school students, but this is juxtaposed with evidence that teachers can learn and accurately present content when they have appropriate instruction, curriculum materials, and professional development (Krall et al., 2009; Nowicki et al., 2010). To that end, a greater focus within preservice teacher education on combining these two elements of directed science content knowledge with classroom practice and evaluation of student ideas is needed. Integration of these pieces can provide prospective teachers with preparation to create the kind of effective science learning environments to increase students' understanding of the natural world (NRC, 2007). While the course and accompanying research results provide evidence that combining science content with elementary teaching practices and research on students' ideas can lead to gains in preservice teachers' ability to engage with students' science ideas, more work is needed to explore this further. In particular, future work should focus how preservice teachers begin to engage more effectively in these practices over time and the extent to which integration of additional science content improves those practices further.

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Appendix A

Examples statements for pre-established codes

Pre-established 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 see 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)