FEATURE ARTICLE

Integrating Life Science Content & Instructional Methods in Elementary Teacher Education

CORY FORBES, JAIME SABEL, LAURA ZANGORI

Abstract

Elementary students need to have meaningful experiences with the life sciences in order to develop understanding of the natural world. However, they often possess alternative ideas about core life-science concepts that may not be scientifically accurate. There is a need for innovative science curriculum and instruction that is responsive to students' ideas, to help students develop a foundation of disciplinary knowledge that will ground their science learning in later grades. Formative assessment gives teachers an important toolkit to elicit, evaluate, and respond to students' ideas. Formative-assessment practices are discipline-specific, in that they require teachers to possess both disciplinary content knowledge and sufficient pedagogical content knowledge (PCK). Unfortunately, formative-assessment practices are not widely used in elementary classrooms; this may be due to elementary teachers' limited disciplinary knowledge and PCK of science topics. Teachers need support in learning how to effectively engage in formative-assessment practices and to integrate the strategies into science classrooms. To address this need, we designed an innovative new course for prospective elementary teachers that integrates life-science disciplinary knowledge with instructional methods – in particular, formative assessment. Here, we describe the course and highlight key findings from its first implementation.

Key Words: *Preservice teacher education; formative assessment; life science.*

To develop understanding of natural phenomena and scientific literacy, students in elementary grades (K–5) should have meaningful experiences with the life sciences, which are a cornerstone of science standards worldwide. In the United States, life science standards for early learners revolve around ecosystem dynamics, inheritance and variation of traits, and organismal structure and function (National Research Council [NRC], 1996; NGSS Lead States, 2013). However, research has shown that elementary students often hold alternative ideas about these core life-science concepts (Grotzer & Basca, 2003; Barman et al., 2006; Anderson et al., 2014). A need remains for innovative science curriculum and instruction that can support elementary students in developing a firm conceptual foundation of disciplinary knowledge and ground their life-science learning in middle school and high school.

> *One way for teachers to support students in confronting their alternative ideas within the life sciences is "responsive science instruction."*

One way for teachers to support students in confronting their alternative ideas within the life sciences is "responsive science instruction." This perspective on teaching locates students' thinking as the primary driver of instructional decision making. A critical assumption of responsive science instruction is that teachers should consistently elicit students' ideas about scientific phenomena. *Formative assessment*, or assessment for learning, is a generalized approach to responsive science instruction that gives teachers a critical toolkit to use in grounding their teaching in students' thinking (e.g., Bell & Cowie, 2001). While many specific formative-assessment strategies have been developed, they all share an emphasis on core components: (a) effectively anticipating and eliciting students' thinking; (b) evaluating students' ideas and diagnosing alternative conceptions; and (c) if necessary, engaging in follow-up instruction that targets gaps in students' understanding. Formative-assessment practices are fundamentally discipline-specific (Coffey et al., 2011), such that teachers must possess not only sufficient knowledge of disciplinary content to diagnose students' thinking, but also sufficient pedagogical content knowledge (PCK) to know how to engage in effective instruction to address gaps in students' understanding.

Research has shown, however, that the use of formative-assessment strategies for science in elementary classrooms is not widespread (Otero & Nathan, 2008; Hammer et al., 2012; Morrison, 2013). Both preservice and in-service elementary teachers may underutilize formative assessment because of limited disciplinary knowledge and PCK for the topics they teach (Heritage et al.,

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2009; Coffey et al., 2011). Teachers must therefore be provided support to develop the capacity to effectively implement formative-assessment strategies for science and cultivate an "assessment for learning" culture in the classroom. To address this need, we designed a new course for prospective elementary teachers that integrates an emphasis on disciplinary knowledge in the life sciences with instructional methods for science, particularly the use of formative assessment. The course is informed by, and builds upon, similar efforts to effectively prepare prospective elementary teachers to support students' learning in the life sciences (e.g., Friedrichsen, 2001; Haefner et al., 2006). The purpose of this paper is to provide an overview of the course and highlight key findings from its first implementation.

○ An Integrated Course for Prospective Elementary Teachers

The newly designed three-credit-hour course engaged prospective elementary teachers in life science content through the lens of K–5 instruction. It was part of an undergraduate program designed to prepare future elementary teachers to effectively foster students' learning. Course goals emphasized both content and pedagogy. The course was grounded in firm theoretical foundations of effective teaching and learning and in research-based methods and strategies to foster teachers' learning.

Programmatic Context

The course is part of a 3-year, undergraduate elementary-teacher-preparation program at a large Midwestern state institution. Historically, the program required students to complete nine credit hours of science, typically fulfilled through introductory science courses offered through science, mathematics, and engineering units, as well as a single, non-discipline-specific elementary-science teaching-methods course. In response to evolving state requirements for elementary-teacher licensure, the teacher education program underwent significant reform. Changes to state licensure requirements resulted in an increase in the course credit hours that prospective elementary teachers were required to complete in science subject areas. To address these changes programmatically, three new courses were developed that integrated (a) disciplinary content and (b) instructional methods for three disciplinary domains: life, Earth, and physical sciences. Here, we report on the first implementation of the life science course.

Theoretical Foundations of the Course

The vision for the course is largely based in perspectives on PCK and, in particular, the notion of *subject matter knowledge for teaching* as proposed by Ball et al. (2008). While knowledge of disciplinary content is generally important, teachers are positioned in the unique role of translating a subset of domain-specific concepts into accessible and meaningful experiences for students. To do this effectively, they must possess more than knowledge of disciplinary concepts alone. Teachers must understand the applicability of specific subject matter in three domains: to *students*, for *instruction*, and with regard to how content is represented in the *curriculum* (Ball et al., 2008). Subject-matter knowledge for teaching is developed in and through professional teaching practice. In the context of the new course, the focus was on supporting prospective elementary teachers' development of life-science subject matter for teaching.

To effectively wield subject-matter knowledge for teaching, teachers should engage in instruction that is responsive to students' thinking. This perspective is embedded within contemporary views of science teaching and learning, which emphasize the role of the learner in constructing knowledge about the world through meaningful, scientific experiences (Donovan & Bransford, 2005; Levin et al., 2009). Within science, this involves engagement in scientific inquiry and the practices of science, such as questioning, investigation, explanation, argument, and modeling (NRC, 1996; NGSS Lead States, 2013). A foundational assumption of this perspective is that students bring preexisting ideas about how the world works to the science classroom (Donovan & Bransford, 2005). To effectively foster students' science learning, their prior knowledge must be engaged through instruction (Levin et al., 2009). Experiences in the classroom both influence and are influenced by teachers' pedagogical reasoning and students' scientific reasoning. Through the practices of science, students should be afforded opportunities to test, reflect upon, and revise their ideas about natural phenomena over time. Figure 1 illustrates a conceptual framework for how responsive science instruction can productively influence students' science learning.

Formative assessment, as introduced above, provides a critical tool through which subject-matter knowledge can be foregrounded for teaching (students, teachers, and the curriculum) in ways that align with Figure 1. It represents an ongoing process whereby teachers elicit, interpret, and use information about students' ideas to shape instruction. It is an overarching heuristic in the design of science learning environments that helps teachers be responsive to students' ideas. First, teachers must possess an understanding of the subject matter addressed in the *curriculum*, and of opportunities within its scope and sequence to elicit students' ideas about related concepts. Second, they must be able to accurately assess *students'* ideas repeatedly in a curricular sequence, identifying not only what students understand, but also where the gaps in their understanding may be. Finally, teachers must possess the requisite knowledge of disciplinary content to both accurately diagnose students' thinking and implement subsequent instruction that is likely to afford students opportunities to confront alternative ideas.

Course Structure & Goals

The course was designed to provide prospective elementary teachers with meaningful and practical learning experiences that successfully prepare them to cultivate elementary-science learning environments that engage students in scientific practices and sense-making about life-science concepts. Students were expected to (1) develop robust knowledge of essential concepts in the life sciences and (2) learn to engage in responsive science instruction that promotes K–5 students' learning of essential concepts in the life sciences. In addition, two questions were posed for prospective teachers to serve as ongoing reflection of activities in the class:

- What are the essential life-science concepts that constitute the elementary science curriculum?
- How can teachers engage in responsive science instruction to ground teaching in students' ideas and support students' learning of these life-science concepts?

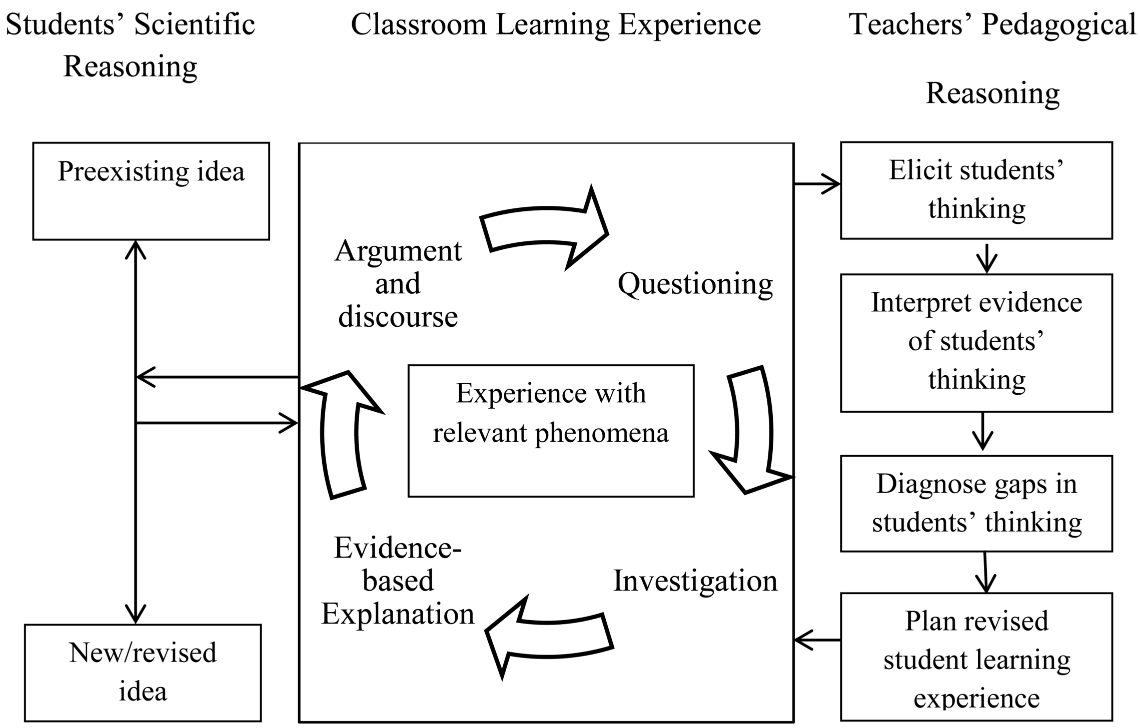

Figure 1. Conceptual framework for responsive science instruction (Sabel et al., 2015).

Students attended two class meetings each week: a whole-class meeting led by the primary faculty instructor (first author) and one of four smaller, facilitated methods sections (all authors). The whole-class lectures involved the use of innovative active-learning strategies to support students' reasoning about disciplinary concepts, elementary students' thinking and misconceptions about those concepts, and related topics. Presentation of information was broken up by frequent opportunities for students to discuss with peers, engage in group problem-solving, and respond to instructor prompts. The smaller methods sections involved students working in small groups to conduct investigations, critique and adapt elementary-science lesson plans, analyze videorecordings of elementary teachers' science instruction, and evaluate student-work samples. Fifty students were enrolled in the course during the first semester it was taught.

Core Course Components

The new course was designed around a set of core components aligned with the guiding questions described above.

Essential life-science concepts. Life-science content in the course was grouped into two 6-week units focused on micro-level (cellular and organismal) and macro-level (populations and ecosystems) phenomena. Curriculum topic study (CTS; Keeley, 2005) was used to support preservice teachers in engaging with weekly focal topics within both units. CTS involves the use of a set of tools and resources that allow teachers to focus on curriculum, instruction, assessment, students' thinking, and their own content knowledge in particular science topics. Predeveloped templates or study guides for each life-science topic point teachers toward subject-matter support; research on students' learning; national, state, and local science standards; and instructional strategies that can inform their instruction about the topic. Although primarily developed for use by in-service teachers during professional development, CTS is also helpful as a strategy to support prospective elementary teachers' integration of life-science content and pedagogy. Each week of the course was designed around a CTS topic, as shown in Table 1.

Table 1. Course units and weekly life-science topics.

Unit	CTS Topic
1 (Micro-level)	Characteristics of living things
	Photosynthesis and respiration
	Mechanism of inheritance
	Plant life
	Fungi and microorganisms
	Human body systems
2 (Macro-level)	Ecosystems
	Food chains and food webs
	Populations and communities
	Habitats and local environments
	Fossil evidence
	Natural and artificial selection

Students in the course independently completed a CTS study guide each week for an assigned life-science topic. Each whole-class meeting focused on supporting preservice teachers to build standards-aligned (NRC, 1996; NGSS Lead States, 2013) life-science content knowledge for specific life-science topics in each CTS study guide. CTS was also used by students to locate grade-level life-science learning targets for K–5 students and to identify and discuss elementary students' common misconceptions about these topics, which provided an opportunity to bridge the gap between theory and practice. As part of methods sections, prospective teachers conducted elementary-science investigations themselves as learners and engaged in discussions about engaging elementary students in investigations within elementary science classrooms. They also engaged in professional teaching practices and participated in collaborations that emphasized student sense-making and scientific practices, such as questioning, investigating, and modeling.

Responsive science instruction. The course was also designed to provide students opportunities to practice engaging in responsive science instruction. This involved a focus on three formative-assessment practices: anticipating students' ideas, evaluating students' responses, and proposing follow-up instruction. Throughout the course, prospective elementary teachers evaluated elementary students' work samples aligned with weekly CTS topics, identified student learning targets in sample lessons, and evaluated and generated cases of "next-step" science instruction in response to gaps in students' thinking. A significant emphasis was placed on identifying practices of science and associated instructional supports through which students can engage productively with life-science topics. For example, as a capstone course project, students completed an analysis of students' ideas, in which they selected a life-science concept and conducted CTS to identify grade-level expectations for elementary students' knowledge of the topic. They then chose or developed a formative-assessment prompt and used it as a foundation for 10- to 15-minute interviews with two elementary students in the same grade. Prospective teachers recorded and transcribed the interviews and then analyzed the elementary students' ideas and presented these findings in a paper and a class presentation. Their analysis and presentations included a discussion of the various conceptions the students had as well as an analysis of how the results might influence how they designed instruction about the concept.

During the semester, students in the course completed three comprehensive formative-assessment assignments. In each of the three assignments, prospective teachers utilized their pedagogical reasoning to think about responsive science instruction in the context of a K–5 life-science lesson plan. The focus of each assignment was aligned with concurrent CTS topics. Assignment 1 was focused on a third-grade lesson on seed dispersal; assignment 2 was focused on a fourth-grade lesson on the skeletal system; and assignment 3 was focused on a third-grade lesson on crayfish habitats. Major prompts to which students responded, as well as formative-assessment domains to which they are aligned, are shown in Table 2.

Completing the assignments required a series of pedagogical reasoning steps. First, prospective teachers in the course responded to a series of questions that elicited their knowledge about life-science content represented in the lesson. They were also asked to anticipate alternative ideas that K–5 students might have about the lesson content, and challenges students might encounter in learning about the content. The prospective teachers then analyzed the elementary-life-science lesson plan for these target concepts, identifying how well they thought the lesson elicited students' understanding. They then interpreted and evaluated real elementary students' work samples from the lesson (obtained from the authors' other research and development projects focused on elementary science) for patterns of student understanding of key concept. The purpose of this analysis was to identify gaps in students' understanding that required further support. The assignments then afforded the prospective teachers the opportunity to make decisions about follow-up instruction to address the gaps they identified in students' ideas about the life-science key concepts. These assignments were completed in an online format during meetings of the methods sections. During the

Table 2. Formative-assessment domains and assignment prompts.

Domain	Prompt
Anticipate students' ideas	What misconceptions or alternative ideas do you think students might have about the key concept of this lesson?
	Given the question the students were asked, what will you look for in students' responses as evidence of their understanding of the key concept?
Evaluate students' responses	What patterns did you notice in the student work you reviewed?
	For 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.
	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.
Propose follow-up instruction	On the basis of 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.
	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?

course meetings, instructors facilitated small-group discussions around questions in Table 2 as students identified target concepts, analyzed lesson plans and student work samples, and proposed follow-up instructional strategies.

Assessment

Prospective teachers in the course were assessed in a variety of methods that reflected the integrated nature of the course's design and goals. These included weekly CTS study guides, formative-assessment assignments, and in-class activities, as well as a precourse and postcourse assessment of their life-science subject-matter knowledge. The items on this content assessment were selected from the American Association for the Advancement of Science's assessment-item bank (AAAS Project 2061, 2013). These AAAS science assessment items are specifically developed to align with CTS topics and include psychometric properties of individual items from administration with different groups of learners, including teachers. Four items were selected to align with each CTS topic in Table 1, yielding an assessment instrument comprising 48 items.

○ Research Findings

To examine preservice teachers' learning within this newly developed course, we conducted a mixed-methods study focused on changes in prospective teachers' content knowledge and ability to engage in formative-assessment practices over the course of the semester. Specifically, we asked (1) What changes are observed in prospective elementary teachers' life-science subject matter for teaching and formative-assessment practices? and (2) To what extent are their formative-assessment practices influenced by their life-science subject matter for teaching? For a full description of methods and findings from this research, see Sabel et al. (2015). Here, we provide an overview of the key results from the study of course implementation.

Data for the study consisted of life-science content exams administered at the beginning and end of the course (n_{pre} = 49, n_{post} = 49), three formative-assessment assignments, and semistructured interviews conducted with a subset of students (n = 10 per assignment, n = 30 total) after each of the three formative-assessment assignments. Pretests and posttests were scored quantitatively. The formative-assessment assignments were scored using a rubric we developed to measure engagement in each of four formative-assessment categories: content knowledge, anticipating student ideas, evaluating student ideas, and proposing next instructional steps. Clinical interviews were used to elicit prospective teachers' thinking about, and understanding of, life-science content and formative-assessment strategies in the context of the formative-assessment assignments. We used quantitative research methods to examine prospective teachers' content knowledge and the effect that content knowledge had on their formative-assessment practices; we used qualitative methods to further examine trends in how prospective teachers engaged in the process of formative assessment as they progressed through the semester (for a full description of research methods, see Sabel et al., 2015).

Preservice Teachers' Content Knowledge & Formative-Assessment Practices

To determine the extent to which prospective teachers' content knowledge and their ability to use formative-assessment practices changed during the semester, we analyzed scores from the pretests and posttests and the three formative-assessment assignments. By comparing subsets of pretest and posttest items aligned with the two course units, we found that prospective teachers' life-science content knowledge improved over the semester for both micro-level (t_{49} = 3.28, P = 0.004, d = 0.71) and macro-level (t_{49} = 5.72, P = 0.001, d = 0.96) life-science phenomena. Results from an analysis of variance (ANOVA) indicated significant variation in aggregate scores on the preservice teachers' three formative-assessment assignments ($F_{2,\ 47}$ = 4.52, P = 0.013). Post hoc analyses using Tukey's HSD test indicated that scores on assignment 2 were significantly higher than those on assignment 1 (at α = 0.05), whereas differences between assignment 3 scores and scores for the other two assignments were not statistically significant. However, these trends varied for underlying, constituent formative-assessment practices. While prospective teachers improved in their ability to anticipate student ideas and evaluate student work over the semester, we did not observe growth in their ability to formulate instructional next steps based on that information. Third, when we examined the relationship between prospective teachers' overall life-science content knowledge and their formative-assessment practices, we found that their life-science content knowledge allowed them to engage more productively in the overall formative-assessment process for the first two assignments, but not for the third assignment. This may be because the format of the third assignment was different from the first two and required prospective teachers to evaluate elementary students' drawn models rather than their written work. This task required prospective teachers to interpret students' ideas rather than look for specific vocabulary words or written ideas that were more directly aligned with their own content knowledge.

Trends in Preservice Teachers' Formative-Assessment Practices

To examine more closely how they engaged in formative assessment, and how their formative-assessment practices changed over the semester, we conducted clinical interviews with 10 prospective elementary teachers from the course after each of the three formative-assessment assignments. In these interviews, students were asked to elaborate on their analysis of students' ideas and description of suggested follow-up instruction from the assignments. Findings illustrate the important role the preservice teachers' knowledge of life-science content played in their formative-assessment practices. Frequently, preservice teachers with less-developed life-science content knowledge relied heavily on concrete terminology identified in the lesson plans and other curriculum materials as leverage points for discipline-specific pedagogical reasoning. Unless elementary students used exact words or phrases in their responses, these prospective teachers had difficulty in deciding the extent to which the elementary students understood the key concept. However, preservice teachers with more developed life-science content knowledge were better able to holistically analyze students' responses to diagnose any gaps in understanding. As the semester progressed, the prospective teachers also improved in their evaluation of students' ideas, and they more often referred to content they had learned in the class or from their CTS guides. Most expressed an explicit self-awareness of both gaps and growth in their own understanding of core life-science concepts emphasized in the course.

The prospective teachers also began to incorporate next-step strategies they had learned in class as the semester progressed. However, the instruction they proposed typically did not refer to specific content with which the elementary students had difficulty, as identified by the preservice teachers in their analysis of student work samples. Overall, regardless of their grasp of life-science content, the preservice teachers tended to propose instructional next steps that were largely discipline-nonspecific. This suggests that engagement in formative-assessment practices helped the preservice teachers begin to consider a wider variety of next instructional steps, but they were not yet able to connect those pedagogical strategies to specific life-science content.

○ Conclusion

In this article, we have described critical elements of an innovative new course designed to support prospective elementary teachers' learning of life-science subject-matter knowledge for teaching and research conducted as part of the course's first implementation. The findings from course-related research are encouraging. They not only suggest that prospective elementary teachers can develop more robust life-science subject-matter knowledge for teaching, but also that they can learn to utilize it more effectively over time to assess and evaluate students' thinking (Coffey et al., 2011). Our results also provide helpful insights into prospective elementary teachers' pedagogical reasoning and contribute to past work that has examined how professional learning experiences that integrate life-science content with pedagogy can help better prepare them for reform-minded elementary science teaching (Otero & Nathan, 2008; Hammer et al., 2012; Morrison, 2013).

However, our results also highlight aspects of the course for ongoing revision. While prospective teachers were able to utilize their knowledge of life-science content to more accurately diagnose students' ideas over time, the same trend was not evident in their proposed strategies to provide subsequent instruction that addressed observed gaps in student thinking. This information is extremely helpful to us as course instructors. One approach we intend to explore in future iterations of the course is to work with teachers to utilize the scientific practices in the *Next Generation Science Standards* as a framework for selecting follow-up instructional strategies to use in the context of formative assessment. Doing so not only provides prospective teachers a concrete guide for instructional strategies that can help target K–5 students' alternative ideas about life-science concepts (Grotzer & Basca, 2003; Barman et al., 2006; Anderson et al., 2014), but also serves a reciprocal role of helping teachers visualize what scientific practices look like in elementary-science learning environments.

The novel course described here provides a model for other courses similarly designed to support prospective elementary teachers' development as teachers of science. We suggest that the research-based strategies, resources, and tools described here (CTS, analysis of student thinking, instructional strategies) provide a right-sized combination of experiences that help novice teachers begin to explore the links between content, instruction, and student learning. This course, and the findings from associated research, join other such efforts (e.g., Friedrichsen, 2001; Haefner et al., 2006) in contributing to an ongoing discussion of novel approaches to prepare future elementary teachers to effectively support K–5 students' life-science learning.

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