

INCORPORATING FORMATIVE ASSESSMENT AND SCIENCE CONTENT
INTO ELEMENTARY SCIENCE METHODS-
A CASE STUDY

by

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ABSTRACT

Just as elementary students enter the science classroom with prior knowledge and experiences, so do preservice elementary teachers who enter the science methods classroom. Elementary science methods instructors recognize the challenges associated with preparing teachers for the science classroom. Two of these challenges include overcoming limited science content understanding and a low science teaching efficacy. Based upon research in science misconceptions, conceptual change theory, formative assessment, and science teaching efficacy, this design experiment explored the use of formative assessment in an authentic learning environment to address some of these challenges. As a case study, the goal was to identify two specific topics in science which the preservice teachers did not understand and to model consistent use of formative assessment to guide instruction in those science topics for six weeks.

The research questions for this study sought to explore the design of the class while also exploring students' understanding of the science content and their understanding of formative assessment. One specific question was whether the formative data could differentiate between deeply held student misconceptions in science and incomplete science understanding. In addition, data was collected to measure changes in science teaching efficacy as well as preservice teachers' desire to use formative assessment in their own future classrooms.

Based upon student interviews and a final content quiz, the participants in this study did show improved science content understanding in the areas of plant food/energy and plate tectonics. The course design implemented a variety of formative assessment tools including formative assessment probes, student science notebooks, student concept maps, a non-graded quiz, and more. The STEBI-B survey identified improved science teaching efficacy among the participants. Student final essays indicated improved understanding of formative assessment and students also expressed a desire to incorporate formative assessment into their future teaching. Final reflections on this case study recognize the value of formative assessment as a means for improved communication between students and teachers about student understanding in an effort to provide and model more effective science instruction.

CHAPTER 1

INTRODUCTION

Teacher quality has a significant impact on student learning in the classroom (Darling-Hammond & Bransford, 2005). In response to concerns about teacher quality in the United States, Arne Duncan, the Secretary of Education, convened The International Summit on the Teaching Profession. Key representatives from over 15 nations met to share and address issues including teacher recruitment and preparation (Stewart, 2011). In July of 2011, the State of Iowa held the Iowa Education Summit entitled “World-Class Education = World-Class Workforce.” The emphasis of the summit was the need to strategically improve equitable learning for all of the state’s students. Iowa is not failing to educate students, but the governor and others recognize that other states have improved considerably, while Iowa has remained the same. Two areas targeted for improvement in the state were the preparation of teachers and the need for enhanced school leadership. A recent *Wall Street Journal* article suggests that teacher-preparation programs need an overhaul (Banchemo, 2010). *Education Week* describes a bipartisan bill called the “Growing Excellent Achievement Training Academies for Teachers and Principals Act” which will require education programs to track graduates’ success in the classroom (Klein, 2011).

Recognizing the need to improve teacher quality leads us to consider areas in need of improvement. When it comes to elementary teacher preparation, two areas of political attention are for candidates to participate in more classroom experience and for states to implement more stringent requirements to enter teacher preparation programs

(Banchero, 2010). However, when the discussion moves towards content knowledge, one of the content areas of concern tends to be science. Studies conducted by science methods instructors describe elementary preservice teachers as having a “high level of discomfort toward the content of science and very little confidence towards the teaching of science” (Jabot, 2002, p. 1). Jablon (1994) and colleagues conducted a survey of their elementary methods students. They found that 95% of their methods students considered science as one of their “least two favorite subjects in school” or their “least favorite subject” in school (p. 155). Citing the Glenn Commission Report of 2000 and years of teaching elementary science methods, Rice and Roychoudhury (2003) suggest that, “In general, elementary teachers exhibit poor science content knowledge, negative attitudes towards science and science teaching and low science teaching efficacies” (p. 119). In addition, the national emphasis on STEM education implies that instructors of science content and elementary science methods must find a more effective way to improve attitudes and increase understanding of science for preservice and practicing elementary teachers.

Teaching elementary science methods for the past six years, I am learning more each year. Obviously, the purpose of a methods class is to improve science teaching. However, the preservice teachers in my elementary science methods class are noticeably different than the preservice teachers in my secondary science methods class. Some of them have limited science content knowledge, lack of confidence, or both. There are some who do not like science or do not see it as important as reading or writing. However, some do enjoy science, have strong science content knowledge and are confident to teach it. One of my goals is to improve the conversation between my

students and me. For instance, “How do I collect and use information about my students to improve my instruction and their learning?” To become more effective, methods instructors need help preservice elementary teachers renew interest, improve attitudes, recognize importance, experience pedagogy, and learn science in a way that will carry over to future elementary classrooms.

Just as we all bring perspectives and experiences into a methods classroom, we need to recognize that children bring their own perspectives of the world into the science classroom. Many of students’ explanations of the world are a result of their personal experiences and cultural teachings. Lists of typical science misconceptions for students of all ages have been compiled and documented for some time (e.g. Driver, Guesne, & Tiberghien, 1985; Driver, Squires, Rushworth, & Wood-Robinson, 1994). Some of these misconceptions are held even after classroom instruction presents the scientific explanations (Schneps & Sadler, 1997). As science educators became aware of these persistent misconceptions, Strike & Posner (1985) proposed the conceptual change model to provide instructional guidance. This classical conceptual change model emphasizes the importance of eliciting cognitive dissonance so that students will become dissatisfied with their incorrect explanations and be more inclined to accept a scientific explanation. Since the introduction of the classical model, the field of conceptual change has become broader and other models have been proposed (e.g. Brown & Hammer, 2008; diSessa, 2006; Vosniadou, Vamvakoussi, & Skopeliti, 2008). In addition, some researchers have questioned the effectiveness of cognitive dissonance for many learning contexts (Limon, 2001; Pintrich, Marx, & Boyle, 1993; Zohar & Aharon-Kravetsky, 2005). Although the conceptual change models vary, one common theme is the need for teachers to elicit and

consider students' prior understanding to assist in guiding instruction. Considering the prior knowledge of preservice elementary teachers, it is also important to note that many preservice and practicing elementary teachers hold science misconceptions as well (Bulunuz & Jarrett, 2009; Crawley & Arditoglou, 1988; Osborne & Freyberg, 1985; Rice, 2005). In a science methods class, good practice should address ways to help elementary students to overcome misconceptions while also considering science misconceptions held by the preservice teachers themselves.

With the federal and state education agencies looking at policy changes for teacher preparation, there are also changes that may need to occur in the methods classroom. Preservice teachers need to experience effective teaching strategies in the classroom rather than just hear lectures about them. One important teaching strategy is the effective use of formative assessment. Education students may be able to define and explain formative assessment, but few may have seen it used extensively. In his recent address to the Iowa Education Summit, Secretary of Education Arne Duncan was asked for specific ways to improve teacher preparation (July 2011). He mentioned two: 1) requiring additional clinical experience and 2) using formative assessment to drive instruction. Formative assessment has been determined to produce increased learning in students. In their influential article on formative assessment, Black and Wiliams (1998) argue that

teaching and learning must be interactive. Teachers need to know about their pupils' progress and difficulties with learning so that they can adapt their own work to meet pupils' needs—needs that are often unpredictable and that vary from one pupil to another. (pg. 2)

Further research on formative assessment has found that imposing a particular method of formative assessment on teachers has not been especially effective. Instead, each teacher must find his or her own way to incorporate formative assessment into their own patterns of classroom work (Black & Wiliam, 2003). Incorporating a variety of formative assessment strategies into science content lessons within my methods course may provide motivation and useful experiences for these teachers to draw from as they establish their own patterns for their future classrooms.

This case study looked at multiple variables in an elementary science methods classroom setting. The research questions were:

1. Building on formative assessment data, how can science methods class instruction be designed and implemented to improve student understanding of science content and formative assessment?
2. How can formative assessment be designed and used to gauge student understanding of both science content and formative assessment in a science methods classroom?
 - 2a. How can formative assessment be used to explore what preservice elementary teachers already know and differentiate between incomplete knowledge and strongly held science misconceptions?
 - 2b. How can formative assessment be used to explore what preservice elementary teachers already know and differentiate between incomplete knowledge and misconceptions about formative assessment?

3. Recognizing that many elementary preservice teachers may have low science teaching efficacy, is there a relationship between increased familiarity with formative assessment and future teachers' science teaching efficacy?
4. How can preservice teachers' experience with formative assessment in a science methods class best be designed to enable them to continue addressing their own understanding of challenging science content as well as their future students' understandings?

The goals of this study included improved implementation of formative assessment, improved understanding of common science misconceptions, and improved attitudes towards science and science teaching of the preservice elementary teachers. Recognizing the complexity of research in the classroom, it seemed appropriate to work within a design experiment (Brown A. , 1992) or design research (Collins, Joseph, & Bielaczyc, 2004) approach. "Design experiments were developed as a way to carry out formative research to test and refine educational designs based upon principles derived from prior research" (Collins et. al., 2004, pg. 15). The actual data collection is much like formative assessment in which a thought experiment is followed by an instructional experiment which is followed by another thought experiment and so on (Gravemeijer & Cobb, 2006). These instructional cycles are guided by a "conjectured local instruction theory" (p. 28) based upon prior research as well as practical teaching wisdom. The goal is to develop effective practice and a revised instructional theory based upon the implementation and the results of the study. The design research approach recognizes the messiness of real-life learning and the need to address multiple variables in the classroom.

The strategies used for formative assessment in this study included probes of student understanding (Keeley, Eberly, & Farrin, 2005; Keeley, Eberle, & Tugel, 2007; Keeley, Eberle, & Dorsey, 2008), concept maps, ungraded quizzes, and student science notebooks. My goal for this study was to utilize various types of formative assessment in an elementary science methods classroom to identify science misconceptions held by students, to reveal incomplete knowledge related to those misconceptions, and to demonstrate the use of formative data to guide instruction. For six weeks, students provided formative assessment data which I used to guide instruction. Changes in student understanding were measured on a pre-post diagnostic survey (American Association for the Advancement of Science, 2011), final quizzes (of which one was used as both a pretest and a posttest), and student science notebooks. Changes in student science teaching efficacy were measured using the STEBI-B survey tool (Riggs & Enochs, 1990). Additional data was collected through classroom observations and a sample of student interviews.

The challenge of this study was to consider the complexity of teaching and learning in the elementary science methods classroom. Educational research continues to guide practice, but learning theory research conducted on individuals does not always transfer to a classroom teacher with twenty students. Considering research from science education, science misconceptions, conceptual change, formative assessment, and teacher efficacy; I attempted to link these areas together to guide instruction in a classroom context. The case was a science methods classroom where students and instructor attempted to learn from each other to become better classroom teachers.

CHAPTER 2

LITERATURE REVIEW

Although it is relatively easy to determine if someone has erroneous understandings, it is more difficult to determine whether the error are due to strongly held science misconceptions or lack of content knowledge. This review of the literature begins with research on science misconceptions and how they have been approached using the conceptual change model and other instructional approaches. Second, research and explanation is presented on how formative assessment provides data and guidance to improve science instruction. Third, as the study takes place in an elementary science methods class, it becomes necessary to explore instructional practice and applications within the science methods classroom. Fourth, it is important to look at preservice elementary teachers, specifically in the area of science efficacy. And finally, the summary connects these areas together providing guidance for this study.

Science Misconceptions and the Conceptual Change Model

Research with preservice and in-service elementary teachers has identified science misconceptions in physical and life sciences (Crawley & Arditzoglou, 1988), earth and space science (Bulunuz & Jarrett, 2009), mass and gravity (Gonen, 2008), and seasonal changes (Trumper, 2006), to name a few. Many of these same misconceptions are held by elementary students (Driver, Guesne, & Tiberghien, 1985) and, indeed, shared by most adult and youth populations.

The research identifying science misconceptions is extensive. Joseph Stepan (1994) has developed a curriculum entitled *Targeting Students' Science Misconceptions*. Rosalind Driver edits an extensive list of science misconceptions in both *Children's Ideas in Science* (Driver, Guesne, & Tiberghien, 1985) and *Making Sense of Secondary Science* (Driver, Squires, Rushworth, & Wood-Robinson, 1994). Based upon Driver's research, the Missouri Department of Elementary and Secondary Education posted 11 pages of *Alerts to Student Difficulties and Misconceptions in Science* (2005). The American Institute of Physics posted online misconceptions in the areas of Astronomy, Atmosphere, Biosphere, Color and Vision, Electricity, Energy, Forces and Motion, Forces and Fluids, etc. (2005). Most recently, the American Association for the Advancement of Science (AAAS) designed a website to provide science teachers with assessment questions to identify and target students' science misconceptions in a number of science topics (2011).

Further evidence of science misconceptions held by college students is presented in the videos entitled *A Private Universe* (Schneps & Sadler, 1987) and *Minds of our Own* (Schneps & Sadler, 1997) produced by the Harvard Smithsonian Center for Astrophysics. These videos demonstrate that students, even Harvard and MIT graduates, have difficulty explaining the cause of the seasons, the workings of electrical circuits, sources of organic matter (wood), and others. As evidenced in these interviews, instruction has failed to help these students adjust their common sense errors to accurate scientific thinking.

Preservice teachers need to be aware of possible science misconceptions in their students while also developing skills to address misconceptions of their own. A case

study by Duschl (1983) depicted pre-service teachers responding to probing science questions in “an uncertain tentative manner, guessing towards the answer, ever watchful for the teacher’s approving nod” (p. 750). He reasoned that the pre-service teachers’ lack of science content knowledge distracted them from learning the science methods. Students were also in conflict over the way in which the methods course was taught, unlike the “usual science class” (p. 751). Duschl states that introductory science courses often teach science as an authoritarian, non-changing subject. The real process of science isn’t experienced until upper-level courses that elementary majors never take. When they enter a good methods class, he asserts, preservice teachers attempt to shore up their science content to “the demise of the methodological and pedagogical objectives of the teacher” (p. 752).

Pre-service teachers are often unaware of the dynamic nature of science. They need to appreciate the cultural and social frameworks that influence the way scientists work to produce a constantly evolving body of knowledge (Baker, 1994). Recognizing Duschl’s concerns that methods students can become sidetracked from learning pedagogy, Baker adds that “a teacher’s capacity to pose questions, select tasks, evaluate pupils’ understanding and make curriculum choices all depends on how they understand the subject matter” (1994, p. 34). It would be optimal if preservice teachers arrived at their methods class proficient in content knowledge. However, in my experience as a science methods instructor, students have continued to learn both as they experience an interdependent mix of content and pedagogy.

Classical Conceptual Change Model

In classrooms and throughout history, people have learned to eventually change their minds when the evidence is overwhelming. Posner, Strike, Hewson, and Gertzog (1982) proposed the conceptual change theory to guide teachers of science to bring about changes in students' thinking from misconceptions to more accurate scientific understanding. Like the scientific community before them, students of science would become dissatisfied with their inaccurate explanations; recognize the new scientific explanation as intelligible, plausible, and fruitful; and switch from misconceptions to the scientific view of the world. Two of their teaching strategies included: "1) Develop lectures, demonstrations, problems, and labs which can be used to create cognitive conflicts in students" and "2) Organize instruction so that teachers can spend a substantial portion of their time in diagnosing errors in student thinking and identifying defensive moves used by students to resist accommodation" (Posner, Strike, Hewson, & Gertzog, 1982, pp. 225-226).

Based directly upon the work of Posner and others, Stepan (1994) presented the Conceptual Change Model (CCM) as a five-step process for changing students' thinking. The first step is to provide students with a situation or problem to solve and to get the student to *commit to an outcome* (verbal or written). The second step is to *expose beliefs* in a small group setting in which students share with each other. The third step is for students to *confront beliefs* or debate their ideas. The fourth step is to *accommodate the new concept* by processing the meaning behind observations. The fifth step is to *extend the concept* to other situations. And finally, the students are asked to *go beyond*, as they continue to think about the concept and ask questions.

This conceptual change model continues to guide science education as is shown in a recent issue of *The Science Teacher* with the article entitled, "From Misconceptions to Conceptual Change" (Gooding & Metz, 2011). The article suggests that teachers begin by identifying student misconceptions, followed by confronting the misconceptions, and conclude by helping students reconstruct and internalize new ideas based upon scientific models. As seen in Table 2.1, the classical conceptual change model continues to influence science education after 30 years. Over time, the science education community continues to recognize it as a useful tool to address student misconceptions in science. Based upon this model, science teachers have been advised to establish this confrontational approach in which teachers find ways to help students identify and then confront their misconceptions.

Table 2.1. The Classical Conceptual Change Model (CCM) applied to science education.

Posner, Strike, Hewson, & Gertzog, 1982	Stepans, 1994	Science Teacher – Gooding & Metz, 2011
Dissatisfaction with existing explanation	Commit to an outcome	Identify misconceptions
New explanation is intelligible	Expose & confront beliefs	Students to confront misconceptions
New explanation is plausible	Accommodate the concept	Students reconstruct knowledge
New explanation is fruitful	Extend the concept and go beyond	Students internalize

Note: The comparisons here include the entire columns and not individual rows.

Although variations of the conceptual change model (Table 2.1) have influenced science education for 30 years, the model has also been the target of criticism. Three main criticisms or alternate perspectives have been voiced. One of the biggest criticisms is the implication of the conceptual change model that student misconceptions need to be completely replaced with the correct scientific concept. Instead of complete replacement, concepts can evolve (Clement, 2008; Wisner & Amin, 2001) as students add new information, distinguish and evaluate ideas, and keep the ideas that continue to fit (Linn, 2008) into their revised framework of understanding. Also instead of replacement, students may need to reorganize and modify knowledge into more correct understanding (Hatano & Inagaki, 2000). A second criticism of the classical approach is the emphasis on promoting dissatisfaction, or confronting students' misconceptions. Clement (2008) suggests using mild dissonance instead of strong confrontation. Duit, Treagust, & Widodo (2008) suggest the emphasis should be on gradual enrichment and restructuring not on "sudden insights facilitated by cognitive conflict" (p. 635). Confrontation seems "destined to undercut students' confidence in their own sense-making abilities" (Smith, diSessa, & Roschelle, 1993, p. 154). A third criticism reacts to the implication that a student either has the right concept or the wrong one. This mindset misses the complexity of student understanding.

Students have a richness of conceptual resources to draw on. Attend to their ideas and help them build on the best of them...I think it is a powerful and useful lesson for teachers to attend to nuances in student ideas, and to try to figure out how to use them productively...it is a losing strategy to focus a lot of energy on teaching students that some particular ideas they have are just wrong (diSessa, 2008, p. 45).

Post-Classical Conceptual Change Models

The classical conceptual change model is not the only one available to guide science misconception education. As research in educational psychology develops, so do variations in ideas about how a student learns to understand scientific concepts. Each alternative model emphasizes different aspects of learning. Some models overlap; therefore each does not provide a unique and independent representation of conceptual understanding (Table 2.2). This paper will introduce four alternative post-classical conceptual change models and then discuss their proposed advice for teachers of science. The four conceptual change models include: the system (or framework) approach, knowledge in pieces, the sociocultural approach, and the complex systems perspective.

Table 2.2. Five Views of Conceptual Change Models

Conceptual Change Model Type	Classical (Posner, Strike)	Frameworks/ Systems (Vosniadou, Chi)	Knowledge in Pieces (diSessa)	Sociocultural Perspective (Pintrich, Mason)	Complex Systems Perspective (Brown & Hammer)
Location of Concept	Mind/ Individual	Mind/ Individual	Mind/ Individual	Social/ Contextual	Individual/ Social/ Contextual
Conceptual Process	Replacement	Evolution	Revision	Development	Complex
Teacher's Role	Prior knowledge, cognitive conflict, provide evidence, expose and confront	Prior knowledge, provide evidence, elicit student thinking, share connections	Prior knowledge, elicit student thinking, help identify and organize pieces	Motivate learners, address anxiety, encourage dialogue, provide experiences	Consider and/or combine the roles suggested by the other models

Table 2.2 Continued.

Student's Role	Become dissatisfied, reject old concept, adopt better concept	Resolve conflicts, revise models, categorize, make connections	Explore fundamental ideas, revise, make connections, organize pieces	Persist, build confidence, choose tasks, contribute, participate, cultural interaction	Consider and/or combine the roles suggested by the other models
How quickly does change occur?	Moment of conversion from old to new ideas	Gradual: adding new information and reorganizing takes time	Gradual: organizing fundamental ideas takes time	Gradual: takes time to interact and participate in cultural practices	Gradual: adding, organizing, and participating

Note. This table summarizes and compares four different models of conceptual change. Adapted from Mayer (2002, p. 108).

Frameworks/Systems The system (or framework) approach reacts to the simplicity of a concept, or the simplicity of a misconception, as if to say that a person either has a science misconception or not. Understanding the world around us begins with personal experiences and beliefs. Each individual makes unique connections between his or her experiences, beliefs, and new information. Personal mental models develop within, and connect to, personal explanatory frameworks in what Vosniadou calls the framework theory approach (Vosniadou, 2007a; Vosniadou, Vamvakoussi, & Skopeliti, 2008). As new experiences and information are incorporated, the learner develops temporary mental models, also called synthetic models, which may change as understanding changes. For instance, when a child learns that the earth is round, having always experienced a flat earth, he/she might create a synthetic model in which people live inside a huge round earth –like walking on the bottom, inside a ball. Vosniadou presented examples of many synthetic models for the earth, based upon interviews with

children (Vosniadou, 2007b). The synthetic model is temporary, and would be a misconception, but it provides the learner with time to reorganize his or her framework until it all makes sense again. Variations of the framework approach suggest an emphasis on mental categorization and student beliefs (Chi, 2008) and/or comparing and exploring connections among various ideas (Linn, 2008). Each synthetic model suggests that science misconceptions are temporary explanations that exist within a larger framework and take time to process and revise.

Knowledge in Pieces The “knowledge in pieces” approach (diSessa, 1988) places a different emphasis on the system described above. Instead of looking at how the experiences, beliefs, and information fit into a larger framework, this approach tries to identify the fundamental understandable elements that make up the concept. In other words, science misconceptions may be based upon faulty elemental pieces (called phenomenological primitives or p-prims) derived from experience. An example of a p-prim is the principle of “dying away” (diSessa, 1988) which applies to the sound of a struck bell or to the speed of a thrown rock. Scientific understanding of bell ringing and rock throwing will require choosing the correct p-prims and organizing them properly. According to diSessa (2008), misconceptions or “entrenched naïve conceptions” result from poorly organized pieces (p-prims) in the mind of the learner and learning is the process of reorganizing the pieces into coherent contextual understanding.

Sociocultural The third approach to conceptual change, the sociocultural approach, explores the affective and social factors that influence learners and learning. These factors include the motivational beliefs of the students as well as the contextual

factors of the classroom (Pintrich, Marx, & Boyle, 1993; Mason, 2007). For instance, motivation will guide learner behavior in task choices, level of engagement, and his or her willingness to persist through the challenge of conceptual change. Other characteristics of learners that may influence conceptual change are achievement goals, belief structures, individual interest, self-efficacy, and emotions (Sinatra & Mason, 2008). Sociocultural researchers recognize that “there is a dialectical relationship between group and individual—the group contributes to the creation of the individual, just as the individual contributes to the creation of the group” (Kelly & Green, 1998, p. 154). The sociocultural approach includes studies of situated cognition as it takes into account the context and the environment in which learning takes place (Vosniadou, 2007a). Much of this research is reacting to the assumption that knowledge is something to be acquired. Instead, knowledge is a process that includes complex individual factors; relational and communal factors; and environmental, cultural, and contextual factors all participating with the learner in the learning process.

Complex Systems Approach The three approaches above can be combined within the complex systems perspective suggested by Brown and Hammer (2008). This perspective describes a dynamic, nonlinear approach to understanding with multiple levels of organization of systems embedded within systems. These embedded systems may include brain research, conceptual frameworks, diSessa’s p-prims, sociocultural perspectives, and/or other explanations of understanding. It suggests that student misconceptions can arise from contextual mistakes or as a result of different language uses. One example is that the term force has different meanings in different contexts

(i.e., being hit by a force, a force field, force and motion, forced entry, etc.). As learning a language is not rigid and linear, so also understanding science needs to be dynamic, flexible, and contextual. As each model or approach provides a unique perspective from which to guide instruction, it is important to recognize that all have some merit and some can be interdependent to provide a more realistic view of the complexity of the learner and the process of conceptual change.

The models described and shown in Table 2.2 are based upon the fields of science education and educational psychology research. The evolution of these models demonstrates both the progress and the complexity of trying to understand learners and learning. Even with such progress and complexity, the conceptual change model that might make it to practitioners is the one explained in the recent NSTA journal (Gooding & Metz, April/May 2011), once again emphasizing the need for teachers to create cognitive dissonance and to make students dissatisfied with their explanations. “In general use, the perspective often degenerates into a general view of students as worse than blank slates; they are slates that have bad ideas written on them in hard to erase chalk” (Brown & Hammer, 2008, p. 131). Instead, teachers need to consider that student reasoning at any particular moment might only apply to that moment and that context. Teachers need to “help students find other possibilities in their existing knowledge, to focus attention on building from productive resources, rather than focus primarily on eliciting and confronting wrong ideas” (Brown & Hammer, 2008, p. 143; see also Gil-Perez & Carrascosa, 1990).

Instructional Guidance for Conceptual Change

Taking the various conceptual change models into consideration should provide significant guidance for instruction, especially in targeting students' science misconceptions. In this section I have tried to synthesize some of the instructional strategies that are repeated or affirmed in the conceptual change literature, even from different perspectives. Recognizing that instructional guidance based upon different perspectives does not guarantee effective practice, the commonality of the suggestions provides greater credibility than any one study or perspective on its own. It should also be noted that I am not attributing a unified set of recommendations for practice to a diverse group of researchers. Recognizing that researchers might not agree with each other, my purpose here is simply to provide a set of instructional suggestions commonly found in the conceptual change literature.

One overarching theme that is repeated in numerous articles is that conceptual change does not appear to happen as quickly as once thought. Changing students' ideas takes time (Clement, 2008; diSessa, 2008; Linn, 2008; Taber, 2001; Vosniadou, Vamvakoussi, & Skopeliti, 2008; Zohar & Aharon-Kravetsky, 2005). Conceptual change instruction in science should also consider the following (in no particular order):

1. Elicit and build upon student prior knowledge (Asoko, 2002; diSessa, 2008; Hewson, 1992; Linn, 2008; Pintrich, Marx, & Boyle, 1993; Vosniadou, Vamvakoussi, & Skopeliti, 2008).

2. Include direct instruction with discovery learning. Used alone, either approach can cause students to develop or reinforce science misconceptions (Asoko, 2002;

Clement, 2008; Gil-Perez & Carrascosa, 1990; Leach & Scott, 2008; Linn, 2008; Zohar & Aharon-Kravetsky, 2005).

3. Implement or demonstrate the use of models—using drawings, play dough, hand motions (Brewer, 2008), mental models (Jonassen, 2008; Vosniadou, Vamvakoussi, & Skopeliti, 2008), and/or concept maps (Jonassen, 2008).

4. Use analogies, especially bridging analogies—a sequence of analogies used to gradually transfer student intuition towards a scientific understanding (Asoko, 2002; Clement, 2008; Linn, 2008; Vosniadou, Vamvakoussi, & Skopeliti, 2008).

5. Help students make connections to different contexts, ideas, and experiences (diSessa, 2008; Linn, 2008)

6. Allow time for student reflection and metaconceptual awareness (Pintrich, Marx, & Boyle, 1993; Vosniadou, Vamvakoussi, & Skopeliti, 2008).

7. Include thought-provoking and engaging opportunities for students such as discrepant events and active class discussions (Clement, 2008; Kang, Scharmann, Noh, & Koh, 2005; Tsai, 2000).

Conceptual Change and Science Misconceptions

The variety of terms and definitions in the literature on conceptual change can be more confusing than helpful. Some researchers make a distinction between conceptual change and conceptual accumulation (Tomita, 2008). Others reject the term conceptual change in favor of concept evolution (Clement, 2008); which explains how a learner selects the surviving concept from a variety of new ideas. The term conceptual profile change (Mortimer, 1995) encourages the teacher to monitor the adaptive process of the

learner by pointing out new evidence, explaining relationships, and identifying obstacles of concept evolution. Carey (1991) suggests that knowledge acquisition can produce a continuum of changes from concept enrichment to concept evolution. The term concept development defines the continual process by which the child's understanding comes to match that of the adult. Hewson, one of the authors of the classical conceptual change model, later redefined conceptual change to include extension – learning new things by adding and making connections to what is already known (Hewson, 1992). Concept development and conceptual change may be completely different or just different points on a continuum. The bigger issue for this study concerns how this distinction, or lack of distinction, applies to teaching in the science classroom.

Classical conceptual change implied the replacement of the wrong idea with the correct one. In the alternative approaches toward conceptual change, the emphasis becomes one of revising or evolving students' scientific understanding. In her description of prior knowledge, Chi (2008) identifies three conditions for student prior knowledge. First, the student may have no prior knowledge of the to-be-learned concept. Second, the student may have some correct knowledge about the concept, but that knowledge is incomplete. Third, the student may have acquired ideas that are in conflict with the to-be-learned concept. In her definition, only the third condition is a case for conceptual change. The first two conditions simply require enriching (Chi, 2008).

Initially, science misconceptions were identified by their persistence after instruction (Schneps & Sadler, 1987). As researchers and teachers considered the value of unveiling prior knowledge before instruction, science misconception research developed tools to identify common student misconceptions (See Appendix B for a

partial list of diagnostic tools). The student misconceptions identified with these tools may be due to any of Chi's three student conditions. Although science misconceptions may be identified from all three conditions, advice for teachers has consistently come from conceptual change research, which only addresses the case of deeply held incorrect student knowledge.

Applying a conceptual change approach to resolve student misconceptions may not always be the best for student learning. For example, there is evidence that conceptual change approaches are ineffective when students lack a threshold level of knowledge about a given topic. In a study of 189 ninth through twelfth graders, Limon and Carretero (1997) determined that presenting students with anomalous data did not produce cognitive conflict nor cause the expected conceptual change. It was also determined that the subjects had inadequate prior knowledge about the topic.

Commenting on the study, Limon (2008) states:

If students have little or no knowledge about a topic, it is difficult to expect any change because their understanding of the new information may be so minimal that the conflict is not meaningful at all. In fact, when prior knowledge is almost none, they are probably not able to recognize it." (p. 367).

In a separate study Chinn and Brewer suggest:

Before students can even begin to evaluate a theory, they need a wealth of domain-specific background knowledge. For example, to offer even an novice's evaluation of the various theories of dinosaur extinction, students need knowledge about meteors, volcanoes, the composition of the earth's interior, the fossil record, geology, geochemistry, methods of measurement, and so on (Chinn & Brewer, 1993, p. 34).

For instructors, the situation becomes a matter of whether the student holds a misconception, has incomplete prior knowledge, or incorrectly communicates his or her understanding.

The goal of the teacher is to facilitate student learning by providing new knowledge and experiences, identifying gaps in student knowledge, and revising incorrect understandings. This requires an interest in and an understanding of, students' prior knowledge and the development of student understanding and communication skills during the learning process. Diagnosing, exploring, and monitoring student learning and communication is the purpose of a renewed teaching strategy called formative assessment.

Formative Assessment

If students are to learn science concepts and to overcome their own misconceptions, teachers of science need to explore ways to learn about student thinking. Recognizing the complexity of conceptual change, teachers are encouraged to elicit student prior knowledge on a particular concept. In fact, there needs to be increased interaction between students and teachers. As teachers learn about student understanding, they are better equipped to provide effective instruction. Learning about student understanding is the task of formative assessment.

Black and Wiliam (1998) define formative assessment as any assessment in which the “evidence is actually used to adapt the teaching to meet student needs” (p. 2). In his book *Transformative Assessment*, Popham (2008) defines formative assessment as “a planned process in which assessment-elicited evidence of students' status is used by

teachers to adjust their ongoing instructional procedures or by students to adjust their current learning tactics” (p. 6). Although the assessment tool could be as informal as a class discussion or probing questions; it can also include formal instruments like concept maps, journal writing, drawings, tests, and quizzes (Buck, Trauth-Nare, & Kaftan, 2009). The identifying characteristic of formative assessment is not the tool. Instead, it is the purpose and the use of the data collected that categorizes assessment as formative.

Ultimately, the purpose of formative assessment is to make teaching more effective for learners. The following are some of the purposes and ways to do this. One purpose is to find out what students already know. At the beginning of a unit, formative assessment can be used to determine what students already know about a topic – student prior knowledge. This allows the teacher to determine the pace of the lesson, recognize the items to review, and consider how to build on previous knowledge and experience. Another purpose is to find out specifically what students do not know. “Formative assessment emphasizes the learning process and closing the gap between students’ current situation and the desired goal” (Yin, et al., 2008, p. 339). After teaching a particular concept, formative assessment can be used to differentiate which students do not understand the concept as well as those who might need advanced challenges. If the assessment tool is well designed, it can also pinpoint which aspects of the material students are struggling to understand. Another purpose of formative assessment is to provide specific feedback to students so that they can see what is needed as they move towards the learning goals of a project or lesson (ASCD, 2008).

Formative Assessment Tools

Recognizing that formative assessment is defined by its purpose, the actual implementation tools can range from formal-looking exams to focused questions asked during class. Other forms could include class discussions, electronic response systems, quizzes, checks for understanding, etc. The most effective formative assessment is preplanned to enhance student learning by focusing the student or the teacher on the content areas where students' learning needs are greatest (Popham, 2008). This section (summarized in Table 2.3) describes some specific tools that can be used to bring formative assessment to the science classroom. The following sections will explain each tool.

Table 2.3. Formative Assessment Tools: Some Useful Examples

Formative Tool	Description
Formative Assessment Probes	Designed to address specific student misconceptions in science. Most probes either force students to commit to an explanation or to select from a list of options. Each probe has a qualitative and quantitative part. (Keeley, 2011)
Peer and/or Self-assessment	Students communicate how they are progressing towards learning targets. (Black, Harrison, Lee, Marshall, & William, 2009)
Science Notebooks	Useful tool to increase teacher-student conversation. Opportunity for individual teacher feedback. (Morrison, 2005)
Student Drawings	Either within student notebooks or individually, drawing provides a useful window into student thinking. (Harlen, 2001)
Concept Cartoons	Like the probes, these cartoons are designed to elicit student commitment to an explanation, correct or erroneous. (Naylor & Keogh, 2000)
Embedded Formative Assessment	Some science curriculum includes tools for eliciting student understanding and suggestions for adjusting instruction. Effectiveness varies with teacher training. (Ayala, et al., 2008)

Table 2.3 Continued.

Concept Maps	With training, students can use these to identify content connections and to identify confusion or gaps in understanding. (White & Gunstone, 1992)
Teacher Feedback*	In response to student work, teacher feedback identifies specific needs (or success) to communicate individual progress back to the student. (Black, Harrison, Lee, Marshall, & Wiliam, 2009)

*Can be used in conjunction with other tools.

Formative Assessment Probes Formative assessment probes are specifically designed instructional tools. These probes ask students questions to uncover their ideas about commonly misunderstood concepts in science. The probes are diagnostic in nature and can be used to identify student preconceptions, lines of reasoning, and learning difficulties. If they are used to inform instruction or to provide feedback to students on their learning (Keeley, 2008), they are considered formative assessment. A series of assessment probes have been developed for use in the science classroom (Keeley, 2011; Keeley & Harrington, 2010; Keeley & Tugel, 2009; Keeley, Eberle, & Dorsey, 2008; Keeley, Eberle, & Tugel, 2007). Each probe addresses a particular topic such as the contents of the bubbles in boiling water. Most probes have two parts, a quantitative part in which students pick the explanation they agree with and a qualitative part in which students explain why they chose that answer. Sometimes students pick the correct answer for the wrong reason or are unable to explain why they chose it. Other students might have a deep understanding, but choose the wrong response. By collecting this type of data, the instructor can identify student understandings and provide specific instruction to fill the gaps in understanding.

The use of formative assessment probes can also be consistent with a sociocultural perspective on learning (Pintrich, Marx, & Boyle, 1993; Sinatra & Mason, 2008). After students have committed to a response, they can talk in pairs or small groups. The goal of these conversations is for them to learn from each other. Students may be more comfortable or more motivated with a peer as they question and defend their answers (Dole & Sinatra, 1998). Explaining why they agree with a particular response, and listening to others' explanations, encourages students to address their own learning, without the voice of teacher authority.

Peer and Self-assessment Although peer and self-assessment is conducted by students, teachers need to provide the time and the structure for it to be effective. Whether assessing their own work or the work of a peer, students can use a teacher-designed rubric to provide helpful feedback during the learning process. In some classes, students are also involved in designing the rubrics to help projects reflect curricular goals (Popham, 2008). It should be noted that students are not ready to take over assessment without some training. For effective peer assessment, teachers need to train students in using assessment tools, working in groups, and communicating criticisms (Black, Harrison, Lee, Marshall, & Wiliam, 2009) and this study did not provide a good example of peer assessment. However, before this study began in my methods class, one day's lesson included an activity in which students were given my lesson plan rubric to provide feedback on a peer's lesson plan. As I walked the students through the rubric, they utilized my assessment tool by comparing a peer's lesson plan before with the rubric's

criteria. Students provided feedback for each other and then were encouraged to use the suggestions to improve their lesson plans.

Science Notebooks Science notebooks are used by students to document class notes, investigation procedures, and data collection as well as student questions, predictions, reflections, and conclusions (Klentschy, 2008). In an attempt to determine what can be learned from students' science notebooks, Ruiz-Primo (2004) converted 5th and 6th grade students' science notebooks from 20 classes into quantitative scores. Based upon these scores, she determined that science notebooks can provide evaluative data for student performance. However, the lack of teacher feedback in the notebooks she evaluated indicated a shortage of teacher training and a missed opportunity for formative assessment (Ruiz-Primo, 2004; Aschbacher & Alonzo, 2006). It was suggested that comments from the teacher could have helped students improve their communication within the science notebook. As it was, student communication did not improve as the notebooks progressed. In response to the studies above, Morrison (2005) suggests including science notebooks in pre-service teacher training. This would "introduce preservice teachers to a beneficial assessment tool, and provide information on preservice teachers' science conceptual understanding and process skill knowledge" (p. 8).

Student Drawings Working with students of all ages, drawings can provide a window into student thinking. Examples include assigning a child to draw the inside of a chicken egg before it hatches or to draw how a person sees the light from a candle (Harlen, 2001). Science is full of models to help us understand phenomena that can't be seen –molecules, light rays, planet orbits, etc. Student drawings provide both a window

into students' perceptions and a great example of how science uses models to explain the world.

Concept Cartoons Chin and Teou (2009) suggest using concept cartoons to determine how well students understand a topic. The cartoons are designed so that science misconceptions and science explanations are included in the cartoon. Students are required to side with one of the characters and justify their position. Then they are encouraged to challenge each other and to discuss why they agree with a particular character. Teachers introduce the cartoons, provide ground rules for discussions, and implement scaffolding for student learning. For instance, one cartoon has children deciding whether putting a coat on a snowman will increase or decrease the rate of melting (Naylor & Keogh, 2000). After viewing the cartoon, the teacher could lead a class discussion to probe student thinking and then encourage further discussion within small groups.

Embedded Formative Assessment Sometimes formative assessment is embedded in the science curriculum materials. With curriculum and assessment developers working together, a series of formative tools were embedded within a *Foundational Approaches in Science Teaching* (FAST) unit. FAST teachers from a variety of schools were trained to include these embedded "reflection lessons" in their classroom (Ayala, et al., 2008). Instruments included graphs, predict-observe-explain activities, short-answer quizzes, and student concept maps. The results did not provide a statistical distinction of improved achievement in the experimental group, but they did show a reduced achievement gap between the high and low performers (Yin, et al., 2008). With 12

classrooms (6 experimental and 6 controls) involved in the study, it was hard to guarantee any consistency among the instructors. Although only the experimental instructors were trained to incorporate formative assessment, the control group may have utilized their own methods of formative assessment in their teaching. Lacking evidence for overall success, the study does suggest that formative assessment is most beneficial to lower achieving students without jeopardizing the learning of higher achieving students.

Teacher Feedback When considering formative assessment, the focus is usually on eliciting student understanding so that the teacher can adjust instruction to fill in gaps between where students are and where the learning goals indicate they should be. By providing specific feedback, students are able to adjust and apply suggestions to subsequent work. One tool that provides students with the information to change their understanding is the use of teacher feedback. As mentioned in relation to science notebooks, teacher feedback is crucial to improved student understanding. Grading alone does not always provide the student with useful information. If the goal is changing student behavior, comment-only marking (without a grade) on student work is most effective (Black, Harrison, Lee, Marshall, & Wiliam, 2009). When students receive returned assignments, they usually want to compare scores with other students instead of reading through teacher comments. Teachers' comments need to provide guidance and details for the students. "good job" does not inform the student why it was good (Black, Harrison, Lee, Marshall, & Wiliam, 2009). In addition, clear learning goals provide students with a target, but feedback lets the student know how they are progressing towards that target (Tagg, 2003).

Other Tools Formative assessment tools can also include a specific use of other instructional tools. Concept maps can be designed by pairs of students to draw out questions they still have. Ungraded quizzes can provide valuable information for both teachers and students. Rubrics, authentic assessment, and SMART board lessons can all provide data on student understanding which can then be used to guide teacher instruction or inform students on their progress towards learning goals.

Formative Assessment and Preservice Elementary Teachers

Since the education community has realized the value of formative assessment (Black & Wiliam, 1998), methods courses are learning how to include it in preservice teacher training. In some cases, formative assessment is presented as just another strategy for instruction, along with inquiry, cooperative learning, using technology, etc. However, a pragmatic approach would suggest that formative assessment must be practiced so that preservice elementary teachers are prepared to utilize it in their own teaching. To do so will require more than just learning about the practice, teachers must also believe in its effectiveness to improve student understanding (James, et al., 2007). The following section will present two studies involving formative assessment and preservice teachers. Each summary will include advice given to other science education instructors and researchers.

Views of Student Knowledge In the science methods class, preservice elementary teachers need opportunities to elicit and incorporate student prior knowledge. A study by Otero and Nathan (2008) addresses this need. In their study, the sample population

consisted of 61 graduate preservice teachers enrolled in three sections of an elementary science methods class. The study took place during a full semester that included a practicum component. The goal for Otero and Nathan (2008) was for preservice teachers to recognize that science knowledge is based on both student content experiences and academic instruction. Reflecting on their results, one of the authors' concerns was that many preservice teachers only value the "academic" aspect of knowledge; they may elicit student data, but only to determine if students "get it or don't." Concepts, vocabulary terms, and objectives are narrowed down to a simple yes or a no. After collecting the formative data, the preservice teacher may simply skip concepts that students appear to already know and add language or concepts to account for the material students do not know. A second concern was that preservice teachers might incorporate both academic and experiential learning in their planning, but the experience is included for other reasons (i.e. meeting multiple intelligences or providing students with fun activities). Although this may help students learn, preservice teachers may not realize the interdependency between students' experiences and academic learning. The ultimate goal for Otero and Nathan (2008) was for preservice teachers to develop a flexible view of student knowledge (academic learning intertwined with experiential learning) which recognizes that students' prior knowledge is changing and misconceptions "may represent steps in the process of coming to understand that concept" (Otero & Nathan, 2008, p. 500). The study suggests that a preservice teacher with this view in mind has the greatest likelihood of incorporating modifications into his or her pre-planned lessons.

Incorporating Formative Data In a different study of elementary preservice teachers, Buck, Trauth-Nare, and Kaftan (2009) wanted to see improved understanding and implementation of formative assessment. To do this, they increased the use of formative assessment in the design of an elementary science methods course. They also added formative assessment to the practicum portion of the class. Throughout the course, formative assessment was used and adjustments were made to the instruction. During their practicum with elementary students, preservice teachers were required to (a) probe student prior knowledge, (b) pick a science topic to develop 5E lessons, (c) embed both formative and summative assessment into the lessons, and (d) collect data and adjust instruction. The researchers also developed four distinct criteria of formative assessment understanding: (a) link formative assessment outcomes to instructional planning, (b) relate formative assessment to students' conceptual development, (c) understand the purpose of formative assessment, and (d) demonstrate an understanding of relational processes inherent to formative assessment. At the end of the course, it was determined that the preservice teachers did improve their understanding of formative assessment especially in criteria one and three. Secondly, it was determined that students were able to collect formative assessment data from students.

In the final discussion, it was concluded that the preservice teachers were unaware of the adjusted instruction within the methods class as a result of the formative assessment (Buck, Trauth-Nare, & Kaftan, 2009). Especially in a methods class, instructors should share how the formative assessment was used to adjust instruction. Second, the study indicated that after collecting student data, preservice teachers struggled with using the collected data to adjust instruction. It seems they found it

difficult to deviate from the planned lesson. Finally, this study recommended that preservice teachers need to reflect upon their own learning experiences and those of the students they teach, especially with respect to the use of formative assessment (Buck, Trauth-Nare, & Kaftan, 2009).

Connecting Science Misconceptions to Formative Assessment

This section will look at how addressing student science misconceptions and using formative assessment have been or could be combined for increased effectiveness. To begin, I will explore the work with science misconceptions in the physics classroom conducted by Jim Minstrell. Secondly, I will show how early methods for addressing students' misconceptions in science seem to align with the purposes of formative assessment.

In the field of physical science education, Jim Minstrell provides an account of his experience with science misconceptions and formative assessment (Minstrell, Anderson, Kraus, & Minstrell, 2008). As a high school physics teacher, he noticed that students seemed to exhibit particular misconceptions on end-of-year tests. To address these particular areas, he made a special point to teach those areas the next year only to find that students still missed those questions. Next, he tried to find out what they didn't understand within a unit and then tried to find new and different ways to improve instruction. This became a pattern (cycle) of gathering student information, interpreting the information, and then acting with purpose to adjust his teaching to address the areas of concern. Over time, the cycle became shorter and more frequent with significant

improvements in student understanding. He later learned that what he was doing was formative assessment.

With the success in Minstrell's class, supporters wondered if the formative procedures could be implemented by other teachers. After procuring funding for research, Minstrell (2008) was asked to find out if student success was a result of his teaching style or his process of assessing for action. He taught his teaching method to two math teachers, who were able to teach physics with similar results after only one year. Next, he trained a group of 12 physics teachers across the state of Washington to implement this cycle of using student information to guide instruction. Students were scored on an end-of-year test with improved results. Initially the variation in student scores was attributed to the variable levels of instructor content knowledge among the twelve teachers. Later it was determined that much of the variation in student scores (5%-35% increase) resulted from the degree to which teachers came to "own" the approach introduced by Minstrell (Minstrell, Anderson, Kraus, & Minstrell, 2008, p. 51). Simply going through the prescribed guide produced improved student scores. However, those teachers who embraced the methodology as a new way to teach saw significant improvement in student scores, particularly in the area of overcoming physical science misconceptions.

Just before Black and Wiliams (1998) were attempting to convince the education community that teachers need to incorporate intentional formative assessment into every classroom, the science misconception community was trying to convince science educators to recognize the importance of eliciting student ideas (Driver, Squires, Rushworth, & Wood-Robinson, 1994). In this seminal work on science misconceptions,

the following list of piloted strategies are given for probing children's thinking: (a) written statements on a topic, (b) student made posters, (c) sorting cards of examples, (d) problem solving projects, (e) student designed experiments, (f) student oral explanations, (g) checklists for comparisons, (h) students predict and explain, and (i) practical experiments. In the actual text, each of these suggested general strategies is accompanied by a specific example to probe student ideas. Many of these same examples are found in formative assessment guides. Probing student understanding and ideas provides the connection between addressing student misconceptions and administering formative assessment. Improving teachers' ability and motivation to consider student understanding will increase the effectiveness of science education.

Teaching Elementary Science Methods

The previous sections have explored the literature on science misconceptions, conceptual change, and formative assessment. As the study takes place in an elementary science methods course, this section explores best practices and guidance for course design and improvement. Teaching science methods to elementary preservice teachers provides both rewards and challenges. The rewards include the growth and development of new teachers for the field, complete with new ideas and effective teaching experiences. The challenges include prioritizing which information to include, creating effective science learning experiences, and encouraging preservice teachers to become prepared, positive, effective, and motivated elementary science teachers. Designing an effective methods course requires knowledge of science content and science pedagogy, along with a collection of assignments, readings, and engaging activities for students. The following

paragraphs will present the pathway to become an elementary science teacher, a framework for teaching science, and strategies for teaching science.

Pathway to Teaching Elementary Science

Mapping a preservice teacher's pathway from childhood to eventually becoming an elementary science teacher demonstrates how elementary science methods provide one component of larger learning framework. Figure 2.1 (modified from Rice 2005) tries to organize the development from prior knowledge to the final product – teaching science in the elementary classroom. In the first phase, *Preparation to teach science*, students are influenced by culture, family, and community. Before taking an elementary science methods course, most preservice teachers have experienced science learning in elementary, secondary, and post-secondary science courses. The “three areas of prior knowledge”: content, pedagogy, and attitudes provide three goals for the elementary science methods class. By incorporating formative assessment into students' learning within the methods class, preservice teachers can experience its usefulness and consider methods of implementation. Finally, the desired outcomes for elementary teachers is that they will know and learn the specific science content for their grade level; they will recognize the importance of spending adequate class time in science learning; they will implement effective science teaching strategies; and they will recognize the importance of their own students' prior knowledge (Bransford, Brown, & Cocking, 2000) and attitudes as they plan and implement science lessons and activities.

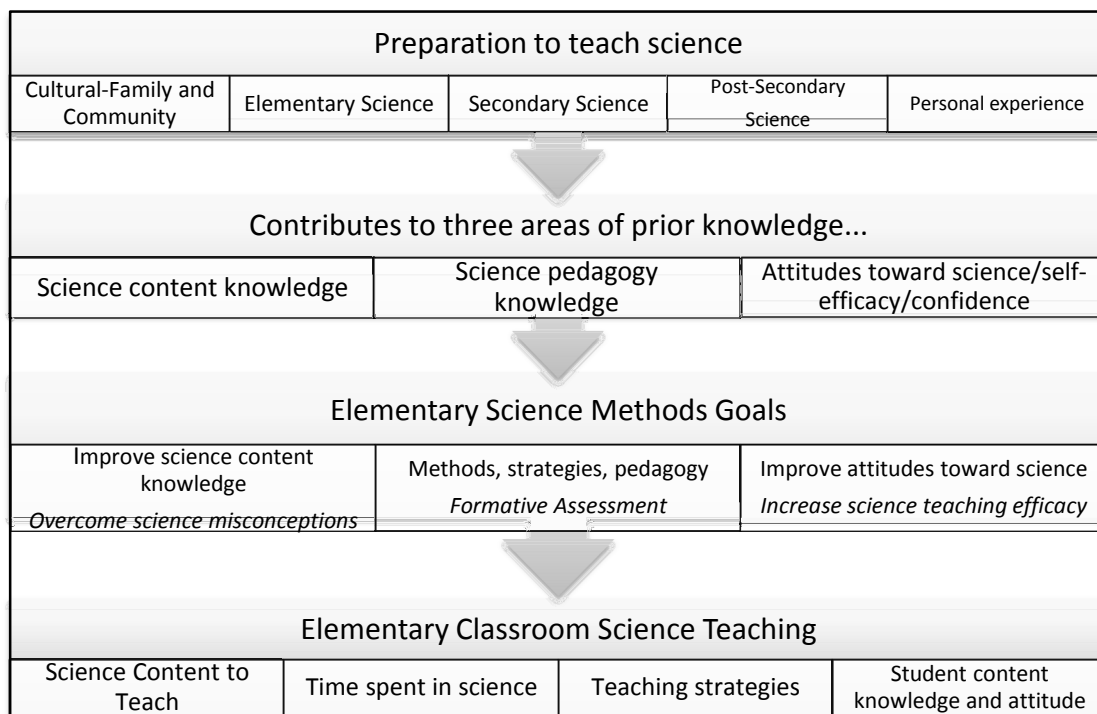


Figure 2.1. Pathway to teaching science. This pathway shows the development of science understanding from childhood, through the elementary science methods classroom, and into teaching science in the elementary classroom. Adapted from Rice (2005, p. 1061).

Framework for Teaching Elementary Science

National teaching standards are written to provide content consistency across the country and to incorporate current educational research into American classrooms. The National Science Education Standards (National Research Council (NRC), 1996) have just been replaced by a draft of the Next Generation National Standards (Achieve, Inc., 2012) for which a conceptual framework was published under the leadership of the National Research Council (2011). The Standards for Science Teacher Preparation were last revised in 2003 (NSTA). These standards continue to place emphasis on the nature of science, the use of inquiry, science in society, and effective assessment. The revised framework continues to recognize that students cannot learn all of science. However, in

addition to content knowledge, sometimes the emphasis needs to be on the process of doing science as well. Hammer and van Zee (2006) explain how this approach to teaching science “reflects how the ultimate goal of science isn’t to arrive at the correct answer to a particular question,” rather it is for students to “construct coherent understanding” (p. 26). In spite of the assessment challenges it provides, this approach to teaching science should also influence our teaching of science methods. Recognizing that it is impossible to cover everything, it becomes necessary to pick specific areas for preservice teachers to develop a deeper understanding.

Teaching Strategies for Science

As frameworks for teaching vary, strategies for preparing teachers do as well. Preservice teachers have had significant experience with direct instruction. With the goal of improving science instruction, a science methods class can go beyond improving direct instruction and also provide teaching strategies which highlight student learning. Additional teaching strategies for a science methods class include classroom investigations (McGlashan, Gasser, Dow, Hartney, & Rogers, 2007), cooperative learning activities (Martin D. , 2006), science notebooks (Morrison, 2005; Ruiz-Primo, 2004), formative assessment (Ruiz-Primo & Furtak, 2007), concept mapping (Martin, Sexton, Franklin, & Gerlovich, 2005), and problem solving (Stuessy & Parker, 1996). The best way to learn about a teaching strategy is to use the strategy for learning or for teaching. This can be done through the implementation of strategies which link and sequence student learning such as the 5E lesson plan (Bybee, 1997) or learning cycle

(Karplus & Thier, 1967) approaches. Such lessons emphasize student exploration, application, and continual assessment (John & Shroyer, 1994; Murphy, 1994).

Preservice Elementary Teachers and Science Efficacy

The most recent revision of the Model Core Teacher Standards, known as the InTASC standards (CCSSO, April 2011) emphasizes the importance of knowing the learner. In light of this emphasis, it seems prudent to look briefly at a few characteristics of preservice elementary science teachers. These college students are predominantly female. In fact, the U.S. graduates in 2008-09 with a BA in elementary teaching were 91% female and 9% male (National Center for Education Statistics, 2010). In a meta-analysis of preservice teachers, one study indicated that over 80% of preservice teachers had been babysitters and most desired to be teachers for altruistic, service oriented goals like helping others and helping children (Brookhart & Freeman, 1992). To be accepted to the education program at the campus where this study takes place, preservice elementary teachers must have a cumulative college GPA above 2.5 and have passed the PPST subject tests in reading, writing, and math. Indeed, the average GPA at the time of entry into the preservice program was 3.34 for the 2010-2011 preservice elementary students. Looking at recent studies, the following sections will explore attitudes towards science followed by research on the science efficacy of preservice elementary teachers.

Attitudes towards Science

Elementary preservice teachers bring their attitudes towards science into the science methods classroom. One common attitude is science anxiety. Administering The

Science Anxiety Questionnaire to all students enrolled in science at a Midwestern university, Mallow (2006) discovered groups with acute anxiety percentages as high as 88% with education majors as the most science-anxious students. Tosun (2000) suggests that many preservice teachers lack confidence to teach science. A lack of confidence to teach science can cause problems with these same teachers as they tend to avoid effective teaching practices (Duschl, 1983). In another survey of preservice elementary teachers, Jablon (1994) records that the majority of elementary and early childhood education students listed science as one of their least favorite subjects in school, felt unprepared to teach it, and many were afraid to teach science in their classroom. Another attitude is apathy towards science as shown by a comment made in my methods class one semester, “I appreciate your efforts to help us understand what happens when water evaporates into the air, but I really don’t care and am completely uninterested in why or how water does that...it just isn’t important to me” (personal communication April, 2011). It is unknown whether this lack of curiosity is typical of the elementary preservice teacher or the result of traditional schooling, but it is not unique to this particular individual. Elementary methods instructors nationwide are well aware of elementary preservice teacher attitudes and numerous studies have tried to develop effective strategies to improve these attitudes (Cox & Carpenter, 1989; Hechter, 2011; Jablon, 1994; Jabot, 2002; Palmer, 2006).

Science Efficacy of Preservice Elementary Teachers

One elementary methods teacher, Jabot (2002), defines low science efficacy as “a high level of discomfort toward the content of science and very little confidence towards the teaching of science” (p. 1). Without science efficacy, a teacher may lack the

confidence to teach science or be hesitant to carry on a discussion with students about science concepts. With numerous studies addressing this issue, there appears to be a lack of science efficacy among preservice and practicing elementary teachers (Czerniak & Haney, 1998; Finson, 2001; Morrisey, 1981; Palmer, 2006; Schoon & Boone, 1998; Watters, Ginns, Neumann, & Schweitzer, 1994). Bandura (1995), who introduced the topic of teacher self-efficacy described its importance in learning:

The task of creating environments conducive to learning rests heavily on the talents and self-efficacy of teachers...Teachers who believe strongly in their instructional efficacy create mastery experiences for their students...those who have low assurance in their instructional efficacy generate negative classroom environments that are likely to undermine students' sense of efficacy and cognitive development. (1995, pp. 19-20).

Research on Science Teaching Efficacy

Teachers with high science efficacy are more likely to use inquiry and student directed teaching strategies. Teachers with low efficacy are more likely to lecture and teach from a textbook while also spending less time teaching science (Czerniak & Haney, 1998). In *Education Update*, a publication from the Association for Supervision and Curriculum Development (ASCD), Allen (2006) claims that the typical elementary teacher does not like science, does not feel confident in his or her knowledge of science, and does not know how to teach science effectively. Obviously, we need to consider science efficacy as we seek to improve the preparedness of elementary preservice teachers.

Some suggestions for improving science efficacy have been studied. In a study with 190 primary education college students, Palmer (2006) explored three factors which might influence their science teaching efficacy: cognitive content mastery, cognitive

pedagogical mastery, and simulated modeling. Of the three, cognitive pedagogical mastery appeared to have the strongest effect on preservice elementary teachers. Another study suggests that preservice teachers need to be provided with experiences in which they observe students successfully learning science (Watters, Ginns, Neumann, & Schweitzer, 1994). Developing teachers will do what they see others doing successfully (Featherstone, Gregorich, Niesz, & Young, 1995). This solution can be encumbered by trying to find effective science teachers in the elementary school for pre-service teachers to observe.

Studies indicate the value of successful experiences in teaching science. If there are opportunities for pre-service teachers to try teaching students science and to measure learning to show that the students have learned, it is suggested that this would help build up their teaching self-efficacy (Watters, Ginns, Neumann, & Schweitzer, 1994). A study on teacher confidence in Singapore defines self-efficacy as an “individual teachers’ beliefs in his or her own capacities to bring about student learning” (Yeo, Ang, Chong, Huan, & Quek, 2008, p. 193). The study claims that the length of time spent teaching plays a strong role in teacher self-efficacy. If teachers have positive early experiences, then they are able to persist through the disappointments and maintain a long-term commitment to teaching; early discouragement can steer people away from teaching (Hoy, 2003-2004; Yeo, Ang, Chong, Huan, & Quek, 2008). A question that is difficult for a study like this to answer, in the absence of longitudinal data including follow-up with educators who have left the field, is whether the low self-efficacy teachers left the profession or if practicing teachers learned self-efficacy through long-term commitment.

Science efficacy can be tied to the limited content knowledge of preservice teachers as well. In a study involving 619 preservice elementary teachers, it was determined that holding particular fundamental science misconceptions correlated with low science-efficacy (Schoon & Boone, 1998). The fundamental misconceptions in their study involved questions from multiple science disciplines such as: space science, evolutionary timelines, chemical reactions, electricity, and geography. The 1997 Committee on Undergraduate Education attributed student conceptual misunderstandings to teaching content while avoiding the confusion between students' preconceived notions and scientific information. As a result, students construct "faulty models that usually are so weak that the students themselves are insecure about the concepts" (Committee on Undergraduate Science Education, National Research Council, 1997, p. 28).

Changing the science efficacy of preservice elementary teachers may require changes in science methods instruction, but it takes time for individuals to change as well. A Turkish study (Tekkaya, Cakiroglu, & Ozkan, 2004) on science and confidence in pre-service teachers ends with an appeal to allow time for pre-service teachers to "explore and try to alter their misconceptions" and also to "find ways to enhance their efficacy beliefs regarding science teaching. Only then can these programs begin to launch future teachers who are ready, willing and able to meet the needs of their students" (p. 65). It takes time to alter science misconceptions, and it takes time to build science self-efficacy. Taking more science courses may not resolve conceptual misunderstandings (Hechter, 2011; Stepan, 1994; Tosun, 2000); yet the need for additional content preparation is evident (Czerniak & Haney, 1998).

Adjustments to science methods courses need to be sensitive to the science efficacy of the students while meeting the goals for effective science instruction. Initially, preservice teachers are just trying to survive and to understand their content. Presenting formative assessment as just another teaching strategy will add to the preservice teacher's laundry list of things to try. For preservice teachers to remember and incorporate formative assessment, they may need to experience learning in a new way. It may be helpful to explore new or confusing content through the lens of formative assessment. Hopefully, this experience will be remembered, and if they recognized its effectiveness, will increase the likelihood of using it in their own classroom.

Summary of the Literature

Targeting misconceptions in science tends to suggest an aggressive approach much like pulling weeds from the garden. The classical conceptual change model, with the goal of replacing wrong concepts, strives to promote dissatisfaction in student ideas by exposing and confronting erroneous concepts. This approach seems to guide teachers towards a confrontational strategy. In some cases, strongly held science misconceptions may require confronting and replacing; however, teachers should recognize that students are in the process of constructing a complex understanding of the world. As teachers learn more about students' prior knowledge, they may recognize that errors in science understanding may also come from incomplete knowledge or missing connections between concepts. Effective teaching in science should elicit student prior knowledge, address incomplete knowledge or missing connections, and reserve conceptual change approaches for persistent, strongly held science misconceptions.

There are numerous teaching strategies to include in an elementary science methods course. Trying to cover as many as possible will provide preservice teachers with tools that they may have not experienced in their own learning. Instead of presenting all strategies as equally valid, instructors of methods classes need to provide guidance and experiences using the most effective strategies. Formative assessment provides the perfect tool to explore student ideas, while guiding instruction towards areas of missing or incorrect student content knowledge.

The target group of this study was elementary preservice teachers. As mentioned above, these students, on the whole, may not be eager to teach science. Many of them have concerns about their scientific knowledge and have limited self-efficacy in science. Elementary science methods classes need to help preservice teachers increase their self-efficacy (confidence) in science, while also considering science misconceptions and content inadequacy.

Moving from theoretical to the practical, the challenge was to explore the combination of targeting science misconceptions, experiencing formative assessment as a teaching strategy, and remaining sensitive to the science efficacy of preservice teachers in the elementary science methods classroom. To begin with, I used diagnostic tools to determine which science misconceptions or content areas were in need of attention. After identifying content areas to explore, formative assessment tools were used to monitor and explore student ideas and understanding of the content. Applying formative assessment results to guide instruction engaged me in identifying students' needs for knowledge acquisition, making connections, or conceptual change. Recognizing that preservice elementary teachers are expected to teach content they may struggle with themselves, I

needed to learn with my students, guided by diagnostic and formative assessment tools. By using multiple formative techniques with the same science topics, the students and I were able to explore, explain, and apply the content in a variety of contexts. Effective science methods may involve learning experiences that might not always work as planned, but this experience provided a unique opportunity to model content engagement and teacher/student interaction with a focus on student learning.

CHAPTER 3

METHODOLOGY

This chapter begins with an overview of the study purpose, and a list of the research questions. Second, the research design is presented including the use of case study and design experiment approaches. Third, the case that was studied is identified with descriptions of the setting, participants and researcher. Fourth, there are brief historical accounts of earlier and current phases in addressing student science misconceptions in this elementary methods class. Fifth, this section examines and justifies the specific methods of data collection and analysis. The final two sections explain the steps taken to ensure quality and credibility throughout the study and to identify potential limitations.

Formative assessment in this study served a dual role. First, it was used throughout the case study to guide instruction. Concurrently, new formative assessments, not foreseen in the original design, were sometimes added as the instruction unfolded. Second, formative assessment was part of the data collection necessary to address the specific research questions of this study. Thus, while some formative assessment techniques are described here in Chapter 3, others are described in Chapter 4 because they belong to my research findings on integration of formative assessment within a science methods class. For this reason, some of the details of specific data collection and applications of the results will be presented in the formative assessment section at the beginning of Chapter 4.

Overview and Study Purpose

This case study explored course design and the implementation of formative assessment in an elementary science methods course. Since I was particularly interested in the application of a new instructional strategy, methodological guidance also came from the literature on design experiments (Brown, 1992). The three main goals of the study included (a) designing the course with an authentic use of formative assessment to support students' learning of difficult science content, (b) helping preservice teachers develop confidence in their science teaching ability, and (c) providing the tools and experiences for students to use formative assessment in their own teaching. After identifying two science misunderstandings held by most of the participants, formative assessment was used to provide data to identify gaps in content knowledge and subsequently to guide instruction.

The research questions were

1. Building on formative assessment data, how can science methods class instruction be designed and implemented to improve student understanding of science content and formative assessment?
2. How can formative assessment be designed and used to gauge student understanding of both science content and formative assessment in a science methods classroom?
 - 2a. How can formative assessment be used to explore what preservice elementary teachers already know and differentiate between incomplete knowledge and strongly held science misconceptions?

- 2b. How can formative assessment be used to explore what preservice elementary teachers already know and differentiate between incomplete knowledge and misconceptions about formative assessment?
3. Recognizing that many elementary preservice teachers may have low science teaching efficacy, is there a relationship between increased familiarity with formative assessment and future teachers' science teaching efficacy?
4. How can preservice teachers' experience with formative assessment in a science methods class best be designed to enable them to continue addressing their own understanding of challenging science content as well as their future students' understandings?

Research Design

Combining the complexity of student learning within the classroom and the focused implementation of instructional strategies necessitates a methodology with flexibility and depth. Relying upon a single data source such as a set of interviews or a set of student surveys cannot provide an adequate picture of classroom instruction, student learning and attitudes. Exploring the learning of preservice elementary teachers within the complex social context of the classroom required the in-depth approach of a case study.

Creswell (2007) defines a case study as “a qualitative approach in which the investigator explores a bounded system (a case) over time, through detailed, in-depth data collection involving multiple sources of information, and reports a case description and case-based themes” (p. 73). In this study, the bounded system is the preservice

elementary students enrolled in the science methods course during a six-week focus on formative assessment to support science teaching and learning. Multiple sources and methods of data collection were used to capture the background and experiences of both students and instructor. These data formed the basis for the descriptions and interpretations comprising this case study. Readers will bring their own experience and understanding to the case study, which will influence their decisions about generalizing the results to their own instructional context (Merriam, 2009).

In addition to incorporating case study design, this investigation was also influenced by design experiment (Brown, 1992) or design research (Collins, Joseph, & Bielaczyc, 2004) in which the researcher designs a solution to a problem and then tries to implement it, often with ongoing revisions, in a classroom setting (Figure 3.1). As the design was implemented, feedback and analysis provided guidance for adjustments within the process. In previous semesters, and during this study, the course went through a number of phases as the design was adjusted and improved.

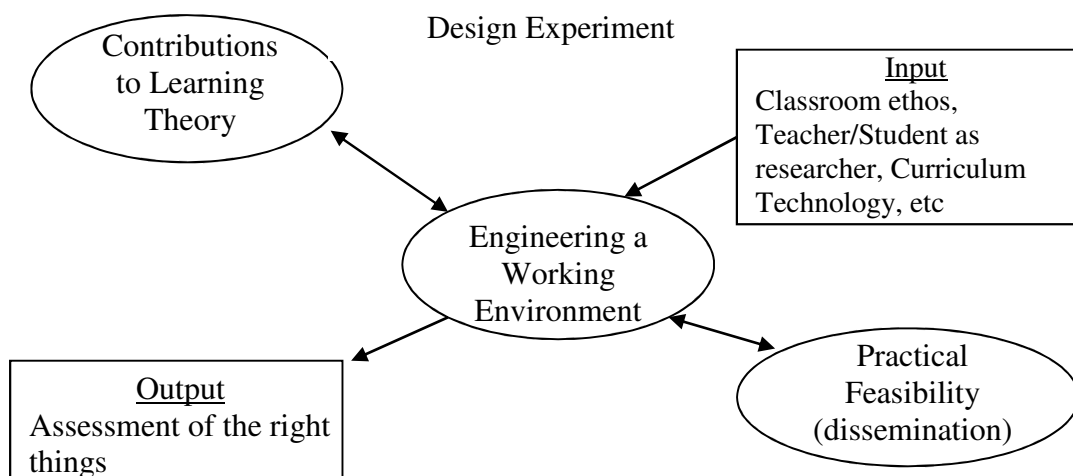


Figure 3.1 Diagram of the design experiment complexity. Adapted from A. Brown (1992, p. 142).

Design research recognizes the complexity of engineering a working environment (Figure 3.1) and the need to try out solutions in the messiness of the classroom (Collins, Joseph, & Bielaczyc, 2004). This approach also seeks to benefit from the wisdom of classroom practitioners (Bannan-Ritland, 2008; Lesh, Kelly, & Yoon, 2008). Available research on science misconceptions, formative assessment, and science teaching efficacy was consulted before the implementation. Those research findings and my teaching experience were combined with formative data results to guide instructional decisions during the intervention.

The complexity of the classroom makes it difficult to establish a control group and to only look at one variable at a time. For instance, in a recent study on the implementation of formative assessment in the classroom (Yin, et al., 2008), researchers used a randomized experiment with 12 classrooms (6 experimental and 6 controls). Curriculum developers embedded formative assessments into a science curriculum, researchers trained teachers in formative assessment, and classroom teachers implemented the material, taking up to a year to complete the material. In the end, the results did not achieve statistical significance on the impact of formative assessment. The strongest explanation for inconclusive results was the difficulty in determining whether or not the control used formative assessment (some control teachers may just use formative assessment without the training) or whether or not the experimental teachers used formative assessment effectively. The comparison was inconclusive in part because of the difficulty in isolating one variable (the effective use of embedded formative assessment). Although each lesson was videotaped, the study could perhaps have been strengthened by including classroom observers during the lessons to verify the distinction

in formative assessment use between the experimental and control classrooms (Shavelson, et al., 2008). Another possibility would be to conduct a design experiment to develop procedures for effective implementation of the embedded formative assessment before conducting the experimental design.

A design experiment approach provided guidance for the methodology for this study in the following ways. First, as a practitioner, I wanted to conduct the intervention within an actual functioning science methods classroom. Recognizing the complexity of the classroom, design research allowed learning to continue in the classroom environment. Second, looking at multiple variables, such as formative assessment, science misconceptions, and science efficacy at the same time was complicated, but it represented a more realistic view of the goals and demands of teaching. While the results did not provide conclusive information regarding success or failure of the approaches implemented, they provided insights into effective and ineffective aspects. Third, as I learned more about design research and learned more about formative assessment, the two approaches seem to complement each other. Both recognize a cyclical approach to learning and the need to incorporate what was learned previously into the next step. Fourth, establishing a design experiment recognized that this study lies within a larger context and is part of an ongoing process. My previous learning experiences in teaching the science methods course influenced this study, and the results of this study will influence my future teaching, and perhaps that of other science methods instructors. The Description of the Previous Phases section (see below) briefly describes what has been done in previous learning phases within my elementary science methods and what was learned in each of them.

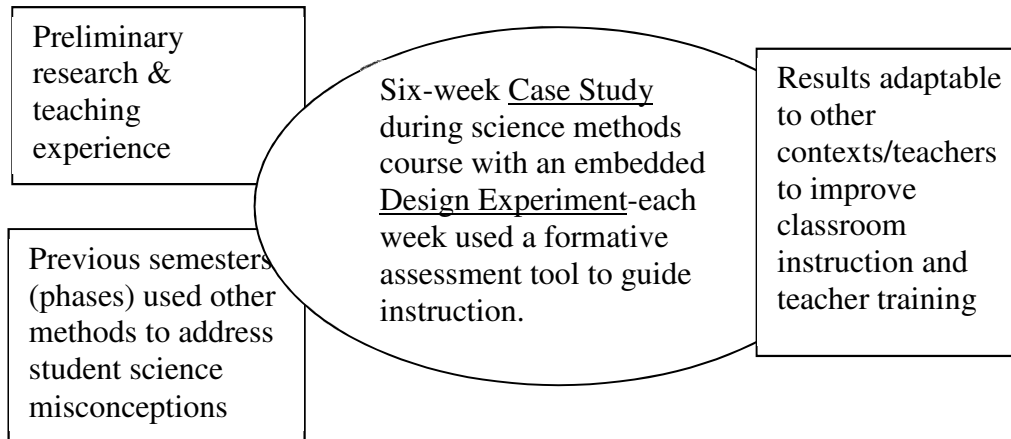


Figure 3.2 Diagram of the interrelationship between the case study and the design experiment.

The overlap between a case study and a design experiment provided a useful tool for data collection and analysis (Figure 3.2). This case study focused on the classroom context, the participants, and me, the instructor. Data was collected to provide a picture of student learning and attitudes towards science teaching and formative assessment. The design experiment focused on the development and application of formative assessment in the classroom as a tool to help preservice teachers overcome their science misconceptions. The design experiment was embedded into the case study by guiding the instructional aspects of the course –using formative assessment each week. Beyond the case study, the design experiment also considered the progress through earlier phases of previous semesters and other methods used to address student science misconceptions. Finally, both the case study and design experiment provided results which can be used for continued improvements and can be adapted to other contexts and by other instructors (Lesh, Kelly, & Yoon, 2008).

Setting and Participants

This case study took place at a small private liberal arts college in the Midwest with an enrollment of approximately 1200 undergraduate students. The class in which the study took place was a 3-credit full-semester methods course for both science and social studies which has one section offered every semester. Students are college juniors and seniors and have been accepted into the education program –requirements include a college GPA above 2.5 and a passing score (state determined) on the Praxis PPST exam in reading, writing, and mathematics. Before student teaching, but not before science methods, each student must complete two college science courses, one in life science and one in physical science. Although my students were juniors and seniors, some had completed both science classes and others had not. In my institution, the education program does not include a specific course for learning assessment; instead the topic is included in the various teaching methods courses.

In this study, there were 24 students (22 females and 2 males) between the ages of 19 and 24, which is a fairly typical gender ratio in an elementary methods class. Many of the students expected to complete their student teaching experience in the following semester. Students at the college are often from rural Midwest farming communities. The campus life is primarily residential with very few non-traditional (older, commuting, or online) students.

In addition to 3 hours of class each week, elementary science methods students are expected to participate in 10 hours of practicum experience during the semester. Typically, each student designs and teaches one or two science lessons to a local home

school co-op group. They also teach one or two social studies lessons to an entire class at a nearby elementary school. The rest of their practicum hours may include classroom instruction, observation, or after school tutoring. The methods classroom was not a science lab room, but it was equipped with a computer, projector, movable tables/chairs, an interactive whiteboard, document camera, and one sink.

Researcher's Role, Background, and Perspectives

In this study, I am both the researcher and the instructor of the elementary science methods class. Committing to both roles may suggest a particular bias or expected results. Instead, this combined role provides me with a unique opportunity to adapt instruction as the data unfolds. Removing all barriers between researcher and instructor provides direct contact with the classroom context. As data is collected and analyzed, the instructor is on board to suggest alternatives or applications which may direct student learning in new ways. As the researcher, I have read and compiled the review of the literature; this background knowledge prepares me to be a better instructor as decisions are made based upon student formative assessment data.

My education background includes two BA degrees, one in philosophy and a second in science education. Recognizing the importance of STEM knowledge in the classroom, I added a secondary endorsement in mathematics and obtained a MEd in technology education, a field with an engineering focus that is distinct from instructional technology. My teaching background includes 12 years in middle and high school science before becoming a college instructor in education. My secondary science endorsements include biology, physical science, chemistry, physics, mathematics, general

science, and earth science. The majority of my teaching has been overseas in small schools where I was responsible for teaching multiple subject areas such as marine science, physics, biology, life science, chemistry, and physical science – although not at the same time. For the past six years, I have been a tenure-track instructor in the education department at a small private college in a Midwestern state. In addition to elementary and secondary science methods, I have been teaching philosophy of education and instructional technology.

My teaching style is pragmatic, trying to find effective ways to improve student learning and encouraging my students to consider ways to do the same. My own instruction is geared towards student engagement, experiential learning, and trying out new ideas. Since watching *A Private Universe* (Schneps & Sadler, 1997) a decade ago, I have tried to address student misconceptions in my science teaching. Experiencing limited success with discrepant events and cognitive dissonance, I wondered if such methods challenged preservice elementary students' science efficacy. Most recently, the potential of formative assessment captured my attention. I wanted to use it as an instructional strategy to help teachers and students to identify specific gaps in knowledge to help overcome science misconceptions. My hope was that addressing science misconceptions with formative assessment tools would improve student learning in science content while improving understanding of formative assessment at the same time.

Descriptions of the Previous Phases

Phase 1 – Student Responsibility

This phase developed for three semesters during the years 2007-2008. With a goal of helping students to self-identify and overcome science misconceptions, a list of common science misconceptions was given to each methods student downloaded from <http://dese.mo.gov/divimprove/curriculum/science/SciMisconc11.05.pdf> (Missouri Department of Elementary and Secondary Education, 2005). This list provided students with common science misconceptions for a variety of science topics. Periodically during the course, students were encouraged to ask questions about any of the misconceptions. These class discussions usually consisted of my explanation of the misconception and how I thought the topic should be understood. The final exam was expected to provide motivation for students to research and study the variety of science misconceptions. The data collected during this phase were student scores on the final exam. Poor test results indicated that overcoming science misconceptions required more than motivating students with test scores. Even with a list of common science misconceptions, students were unable to self-identify the misconceptions they held.

Phase 2 – Discrepant Events and Student Lessons

This phase was developed for three semesters-during the years 2009 - 2010. The goal was still to help students overcome science misconceptions. The results from Phase 1 indicated that students were not able to self-identify their own misconceptions and they were unable to overcome the misconceptions on their own, a change was made in the structure of the class. According to the conceptual change model (Posner, Strike,

Hewson, & Gertzog, 1982), students need to experience dissatisfaction with their own thinking. This phase thus included adding a number of discrepant events to the class. Each discrepant event was connected to a number of related science concepts, experiences, or perceptions (Tsai, 2000). For instance, students were shown a discrepant event using surface tension to move a paper boat across water. Related concepts included polar bonds, surface tension, bonding, properties of water, etc. These topics were identified by me and each was discussed in class. In addition to the discrepant event lessons, students were given topics to teach to the class. The topics were specific areas of misconceptions in which the previous classes did poorly on the final exam. Topics included gravity, moon phases, decay, animals, plant food, and reasons for the seasons. These lessons provided varying degrees of success. Students who planned ahead and met with me before teaching were able to present the material more clearly and this may have helped clarify some misconceptions. However, the “last minute” students often found themselves struggling with the material during teaching which made for awkward situations. Their content inadequacy may have also increased their fears and anxiety towards teaching science. Data collection in the final exam switched from a wide range of science misconceptions to essay questions asking students to explain the concepts taught by peers. In Phase 2, the results were better, but still unsatisfactory.

Phase 3 – Using Probes and Notebooks

This phase was developed during the 2010-2011 school year. The goal of Phase 3 was still to help students overcome their science misconceptions. The challenge in Phase 3 was to apply more current conceptual change approaches to student misconceptions and

also to consider student self-efficacy in teaching science. The tools used to address science misconceptions were a series of formative assessment probes taken from *Uncovering Student Ideas in Science vol. 1-4* (Keeley, Eberle, & Dorsey, 2008; Keeley, Eberly, & Farrin, 2005; Keeley, Eberle, & Tugel, 2007; Keeley & Tugel, 2009). Each probe (Sample in Appendix A) provided a window into students' thinking. The probes were designed to reveal science misconceptions held by students. It was interesting to watch students discover that the person next to them had a different answer on his or her probe. Discussion ensued, and then groups combined to include more students. Sometimes students learned from each other which answer provided the best explanation. Sometimes the discussion led to an activity, sometimes students left class frustrated. The probes brought thinking out into the open. They were not designed to be graded; instead they provided opportunities for student learning and guided instruction.

For example, one probe asked about what happens to the water that leaves a pair of jeans hanging out on the line. To convert the probe to an experience, I installed a clothesline in the room with a wet shirt hanging out to dry. Each student was encouraged to touch the shirt and feel how wet it is. Students were given a probe that provided seven possible explanations for where the water goes when it leaves the wet laundry. There was also space for students to explain why they made the choice they did. The wet shirt was left on the line until the next class meeting where students touched the dry shirt and continued the discussion about water going into the air. Interesting enough, most explanations consisted of the word, "evaporation", which is not really an explanation at all. The class discussion moved towards the problem of teaching science as vocabulary terms and how terminology does not provide understanding (Duckworth,

2006). In follow-up discussions we talked about the water molecule, phase changes, and invisible water in the air. One activity included using flashlight batteries to split water into hydrogen and oxygen. Later in the course, hoping to confirm students' knowledge of phase changes, I gave students a different probe which asked about the bubbles formed in boiling water. Surprisingly, only five students (out of 16) indicated that the bubbles in boiling water were filled with "an invisible form of water". Most of the students suggested the gas was air or hydrogen and oxygen. One student explained that the energy of boiling was like the energy of electricity so the gas must be hydrogen and oxygen like it was with our battery electrolysis. This led to further discussion and demonstrating the tests for oxygen (glowing splint) and hydrogen (burns with a pop noise). I also visited with a chemistry instructor to learn the importance of the electrons in electricity for splitting water into hydrogen and oxygen. Boiling water uses lots of energy, but without the electrons from electricity, the change is only physical (liquid into steam) and not chemical (water into hydrogen and oxygen).

During Phase 3, data collection switched to science notebooks in which they answered questions, reflected, commented on activities, collected experimental data, and explained science in their own words. Students were encouraged to provide evidence of their knowledge and evidence of their learning. I collected the notebooks once and provided feedback to each student. One of my common comments was "how can I tell what you are thinking or what you learned unless you include it in your notebook?" After the feedback, notebook use increased and entries were more detailed. The use of these formative assessment probes and student science notebooks was a pilot for Phase 4, the object of this study. The results indicated that neither method provided complete

understanding. The student notebooks and the formative assessment probes provided guidance for student conversations as well as my instruction. With this in mind, I wanted to include a variety of formative assessment tools in the next phase.

Overview of the Present Study – Phase 4

The design experiment comprising the core of this study took place during six weeks of the science methods class during the fall semester of 2011 (Table 3.1). In any design experiment, the instructional treatment and findings are intermixed to a great degree, since formative results are used to modify what is occurring within the instruction. Given the reality that treatment and results are tightly integrated in this study, a general overview of the Phase 4 treatment will be given here, and the details will be given in Chapter 4.

During Phase 4, my elementary science methods class met on Monday, Wednesday, and Friday for 50 minutes. During this phase of the study, each Monday included gathering specific formative data, Wednesdays were reserved for the development and delivery of student designed lessons, a process that could not always be synchronized with the design experiment, and each Friday included instructional strategies based upon Monday's formative data. At the start of Phase 4, a diagnostic instrument was used to identify specific science topics which this particular class of students did not understand well. A second diagnostic survey was used to gather initial data on elementary preservice teacher science teaching efficacy. Recognizing that elementary science content standards (national and state) include most areas of science, the first purpose was to identify two to four science content topics that the students in the

class misunderstood – although at this point, it was unknown if their misunderstandings were due to gaps in knowledge, well-developed science misconceptions, or both.

Subsequent formative assessment focused on those content areas. Secondly, the science diagnostic and the science teaching efficacy survey were used for comparative purposes at the end of the course. The results are presented in the next chapter, but because they determined my instructional approach, results from the diagnostic survey are included in Table 3.1.

The purpose of the diagnostic survey was to determine which of 14 science topics commonly taught in elementary school were most frequently missing from students' knowledge. After determining which content areas to study, formative assessment was used on a regular basis throughout this six week phase. For each week (Table 3.1), a formative method was used in Monday's class to collect data, which was then used to guide instruction in Friday's class.

Table 3.1. Connection between Formative Assessment and Instruction for the six weeks of the Intervention.

Week	Formative Tool on Monday	Learning Experiences on Friday
1	Formative assessment probes address food and chlorophyll	Connecting human food to plant food Overview of photosynthesis
2	Probes address where and when plants make food	Students demonstrated understanding, led to using concept maps on Wed. and students acted out the process of photosynthesis on Friday
3	Non-graded quiz on photosynthesis	Lesson addresses student questions from quiz with further discussion and closure
4	Pretest on plate tectonics	Engage students in plate tectonics with video clips, faith aspects, and relating the topic to living in the Midwest

Table 3.1 Continued.

5	Student self-reflection	Students explore and learn about plate tectonics through online videos, tutorials and simulations.
6	Student choice – summary or concept map to produce questions	Lesson based on student questions; looked at evidence and used science notebooks to diagram plate boundaries,

A variety of formative assessment and data collection tools were utilized during the course. Students kept a science journal, completed formative assessment probes, created concept maps, and took a non-graded quiz. At the end of the course, students completed summative essays on their understanding of formative assessment and designed a formative assessment application. A quiz was given to measure student content understanding. Pre, during, and post-Phase 4 interviews were conducted with a sample of students from the class and a later interview was conducted with a sample of former students, including students from the Phase 4 and previous classes, during their student teaching experience.

Methods of Data Collection and Analysis

This section begins with a matrix connecting each research question to the data collection tools (Table 3.2). In the text that follows, each data collection tool is described, along with the reason for its selection, a description of how the tool was administered, and the methods of data analysis. Recognizing the flexibility of a design experiment within a classroom context, consideration was given for modification of data collection or implementation even while the implementation was in progress. Such modifications will be explained in the next chapter.

Table 3.2. Matrix of Research Questions and Data Sources

Research Question	Data Collection Tool	Data Analysis	Timeline
1. Building on formative assessment data, how can science methods class instruction be designed and implemented to improve student understanding of science content and formative assessment?	Student Science Notebooks – Entries reflecting upon the formative data collection and teaching strategies	Categories identified and student responses compiled	October- November 6 weeks of instruction
	Course documents Class observations	Categories identified and student responses compiled Student behavior	December 3 visits
2a. How can formative assessment be used to explore what preservice elementary teachers already know and differentiate between incomplete knowledge and strongly held science misconceptions?	AAAS Diagnostic Instrument – 40 multiple choice questions from online database of common misconceptions Formative Assessment Probes & Student Science Notebooks – sequence of entries for each content area	Pre and posttest comparisons. Student answers will be coded and compiled to determine paths of understanding and to identify gaps in understanding	September – Pretest November - Posttest October- November During 6 weeks of instruction
2b. How can formative assessment be used to explore what preservice elementary teachers already know and differentiate between incomplete knowledge and misconceptions about formative assessment?	Student Science Notebooks	Student entries will be coded to show progress of student understanding	October- November 6 weeks of instruction
	Course documents Question/reflections Student interviews	Responses used to verify course documents	October- December

Table 3.2 Continued.

3. Recognizing that many elementary preservice teachers may have low science teaching efficacy, is there a relationship between increased familiarity with formative assessment and future teachers' science teaching efficacy?	Science Teaching Efficacies Beliefs Instrument, Form B (STEBI-B) Interviews	Compare pre and post test results for the class for the two subscales – PSTE and STOE	September -Pretest November – Posttest
	Student Science Notebooks	Student responses to questions about teaching science	October- November
4. How can preservice teachers' experience with formative assessment in a science methods class best be designed to enable them to continue addressing their own understanding of challenging science content as well as their future students' understandings?	Instructor Journal Student interviews Final Exam reflections Student Teacher Interviews	Responses and entries used to identify effective practice from the learning experience or anticipated applications for the future.	October- December

AAAS Science Assessment

This diagnostic test was used for both the identification of specific science content to be addressed in the methods course and an indication of growth in understanding. The intent was to pick two or three specific science concepts which the students in the class did not understand. Secondly, the diagnostic test was used as a pre/post test to measure growth in student understanding of those science topics. Appendix B is a table of other potential diagnostic tests (alphabetical) which I reviewed that have been developed for a variety of age levels and content areas. Some of the tests require registration, one requires payment.

In this study, I was looking for a tool that provided an overview of misconceptions including the three areas of science –life, physical, and earth/space. The AAAS website (American Association for the Advancement of Science, 2011) provides a free personal account to educators. The site lists major topics within each science area. Each major topic is divided into key areas. Each key area has three tabs. The first tab lists the sub-ideas that students are expected to know. The second tab lists knowledge items for the topic. Each knowledge item can be chosen as an item for the item bank (diagnostic test). The third tab lists specific misconceptions relating to the topic with research references and the response norms for students choosing the misconception in the field test for both grade categories 6-8 and 9-12.

To create a diagnostic test, an instructor selects a topic and then selects items for his or her item bank. The item bank becomes a multiple choice diagnostic tool complete with tables and graphs for each question from the field study of AAAS (Appendix C). Pilot testing included 100 students in each group, field testing included about 1000 students from grades 6-8 and another 1000 students for grades 9-12. The tables and graphs show distribution of responses, frequency of each choice with breakdowns for grade, gender, and primary language. Considering the newness of the site (2010), the extensive field testing, the adaptability for different content, and the convenience of online availability, I decided to use the AAAS science assessment website to build my diagnostic tool. Although the website provides questions for a wide range of topics, the test I designed chose 2-3 questions from a variety of topics representative of the K-8 science standards in the state where this study took place.

The diagnostic test was given to each student before beginning the 6-week intervention and a portion of it was given again after the intervention. The answers were scored on a multiple choice answer sheet to be used with a GradeMaster scanner which also provides item analysis. The item analysis includes frequency of correct answers (and thereby frequency of incorrect answers) as well as frequency of each answer choice.

The diagnostic test served multiple purposes; to determine the most frequently occurring incorrect answers, to measure changes in understanding, and to model formative assessment for the students. After students completed the diagnostic test, the frequencies of each incorrect answer helped determine the topics to study (see Chapter 4). The results and the instructional decisions were discussed with the class to carry on the goal of applying and learning from formative assessment. Secondly, after the intervention, a portion of the test was given again to identify any changes in overall student understandings, especially the topic areas addressed in the class.

Science Teaching Efficacy Beliefs Instrument-Form B (STEBI-B)

The STEBI-B (Appendix D) is a survey designed (Enochs & Riggs, 1990) to test the science teaching efficacy of elementary preservice teachers. The survey was used as a pre/posttest to measure changes in student science efficacy during the intervention. Students are asked to self-identify their response on a 5-point Likert-scale ranging from strongly disagree to strongly agree. The results are divided into two subscales; the Personal Science Teaching Efficacy (PSTE) Belief Scale which measures a preservice teacher's personal confidence to teach science and the Science Teaching Outcome Expectancy (STOE) Scale which measures the preservice teacher's expectation of

students' ability to learn science in his or her classroom. The designers of the instrument determined reliability alpha coefficients of 0.90 and 0.76 for the two subscales (Enochs & Riggs, 1990). This tool has been used in numerous studies on science teaching efficacy of elementary preservice teachers (Finson, 2001; Hechter, 2011; Joseph, 2010; Ramey-Gassert, Shroyer, & Staver, 1996; Watters, Ginns, Neumann, & Schweitzer, 1994). After considering a variety of instruments used to assess attitudes and self-efficacy towards science and science teaching, I chose to use the STEBI-B because it is written for elementary preservice teachers, it has strong reliability scores, and it has been used extensively in similar studies.

The STEBI-B was given to each student before beginning the six-week intervention and again after the intervention. The STEBI-B is broken down into two subcomponents, the PSTE and STOE. Of the 23 questions, 13 items were used to calculate each student's personal science teaching efficacy score which has a range of 13-65. The remaining 10 items are used to calculate each student's science teaching outcome expectancy which has a score range of 10-50. A paired sample t-test was used to compare pre and posttest.

Science Notebooks

Each student was given a science notebook (Aschbacher & Alonzo, 2006; Klentschy, 2008; Morrison, 2005) to use for the duration of the course. The notebooks provided data on students' understanding of formative assessment, science content, and their initial attitudes towards teaching science. Students used the notebooks to write questions about science topics, to take notes, to answer questions, to collect data for class

investigations, to record reflections on readings, and more. Appendix I includes a list of the assignments and entries in each student's science notebook for the semester. The notebooks provided a glimpse into student thinking, so at times, they were also asked to write predictions, explanations, and/or frustrations. During the intervention, notebooks were collected every two weeks for formative assessment through teacher feedback. In the feedback, many students were told to provide more information or detailed explanations so I could see what they were thinking. At the end of the course, students were encouraged to use entries from their notebook to demonstrate evidence of their learning or changes in their understanding.

Students were asked specific questions relating to formative assessment. They were asked to define formative assessment and to describe what formative assessment would look like in their classroom. In addition, a variety of formative assessment techniques were assigned to explore understanding of the science topics. These assignments included diagrams, concept maps, and non-graded quizzes. Analysis of the notebooks was continuous during the intervention (every two weeks); phrases from student notebooks were arranged on a spreadsheet to explore patterns in student understanding or misunderstanding. The science notebooks were used for formative assessment purposes (Aschbacher & Alonzo, 2006; Morrison, 2005) and data collection.

At the beginning of the course, students wrote a science autobiography that included their attitudes and confidence towards science and teaching science. At the end of the course, students wrote a short essay about their learning experience in the class, with emphasis on their science understanding, formative assessment, science confidence

and attitudes towards teaching science. These entries were used to understand changes in student attitudes and science efficacy.

Formative Assessment Probes

Other tools used in the course were the formative assessment probes designed by Page Keeley et al. (Keeley, Eberly, & Farrin, 2005; Keeley, Eberle, & Tugel, 2007; Keeley & Tugel, 2009). The probes provided data on student understanding of the science content, and were also used as instructional tools of formative assessment. Most of these probes have two parts (See example in Appendix A). The first part of the probe asks the student to choose a best answer from selections that include common student misconceptions. The second part has the student explain why that choice was made. Some probes have a list of items for categorizing, such as living or non-living items. Then, the student is asked to explain what criterion was used to make the decision. After completing the probe, the students might pair share, group share, participate in a class discussion, or all three. The probes were often given to students during class on Monday or as homework to be turned in on Wednesday and then used to guide instructional decisions for a Friday learning activity. Also during the intervention, students were shown classroom responses with response patterns. This allowed them to see formative data and instructional applications.

Science assessment probes were analyzed throughout the intervention. The first part of the probe (quantitative) indicates the frequency of correct or incorrect answers. Analysis included frequency histograms. The second part of the probes asks students to explain the reasons for their answers. The analysis involved identifying the nature and

levels of understanding by mapping missing information (gaps) and incorrect understandings (misconceptions) for individual students and the class as a whole.

Instructor Field Journal

Before and after each lesson, I wrote my goals and reflections into an instructor journal. The goals identified the instructional strategy of the lesson and in what ways it is based upon practical experience or formative assessment data. After each lesson, I tried to answer intuitively any questions about student learning in the lesson and to evaluate what went well and what could have been improved.

Classroom Observations

For three of the lessons, an undergraduate research assistant joined the class to provide a record of student interest, engagement, and conversation. The campus where the study took place does not offer graduate programs, and thus there is not a pool of advanced students with a higher level of classroom or research experience. Instead, an undergraduate research assistant familiar with the class was asked to assume this observer role. During observations, she sat in the back, observed and took notes, with as little intrusion as possible. The three lessons included implementations of teaching strategies based upon the formative assessment data. The observer's first goal was to capture the dialogue of the learning experience between the teacher and the students. The second goal was to monitor student engagement. Was everyone paying attention? How many students were not paying attention and at what times in the lesson? The third goal was to gauge students' response to the formative data. As the formative results were shared, the observer tried to identify student buy-in to the results – and to identify any evidence of

those who disagreed with the results. Much like the instructor's field journal, this data was used for triangulation with student explanations of science or formative assessment in science notebooks and student interviews.

Interviews with Students

The interviews were conducted to provide additional data on student understanding of the science content and formative assessment. Students were also asked about their attitudes towards teaching science and their expected use of formative assessment in the future. Seven students from the class were chosen for interviews based upon typical case sampling (Patton, 2001). Each selected student was interviewed three times (pre, during, and post intervention) by either the instructor or the research assistant. Questions asked during the interview were based upon the research questions and followed the interview guides (Patton, 2001) included in Appendix H. The interview guides were developed from the research questions and sent to a university science educator and an educational psychologist familiar with the study for feedback. A practice interview was conducted with my research assistant and the questions were adjusted again for clarification. The interview guide was adjusted for each round of interviews.

During the interviews, students were asked to share about the perceived effectiveness of formative assessment for their own science learning in this course. The interview included questions about student understanding of the science content addressed in the lessons. Finally, students were asked how the formative assessment experience influenced their own teaching expectations and attitudes in the area of science education. The interviews were recorded and converted to transcripts. Relating back to

the research questions, interview transcripts were used to identify patterns and themes in student thinking. Results of the interviews were also triangulated with data from other methods and sources.

Recognizing that student teaching can provide a precursor to actual classroom teaching, interviews with student teachers were conducted during the semester following the course. These student teacher interviewees were all previous members of the class. Some had participated in the design experiment during Phase 4; others had been in the class during one earlier semester. All interviewees were engaged in student teaching in the semester immediately following Phase 4, and responded affirmatively to my request to participate in this final round of interviewing. Similar to the previous interviews, an interview guide was prepared (Appendix H) based upon the research questions and the use of formative assessment. A draft of the interview guide was sent the same university faculty members for feedback before the interviews were conducted. The purpose of this set of interviews was to determine if student teachers were using formative assessment, and if so, how and for what reasons. The interviews were also used to provide further data on candidates' likelihood of using formative assessment for enhancing their own students' understanding of difficult science material (Research Question 4).

Course Documents

At the end of the course, students were given a number of final exam questions which related directly to the research questions of the study. These essay responses were used to determine the attitudes of the students, the final indication of content understanding, and final explanations of formative assessment. The preservice teachers

were also asked to reflect upon the learning experience and to predict the likelihood of incorporating formative assessment into their own teaching. To demonstrate student understanding of formative assessment, students were asked to design a unique formative assessment learning experience for a future classroom. This written feedback was used to compare with other sources of data to verify the consistency of research interpretations.

Quality Controls

The first quality control was the use of multiple data methods and sources of evidence (Patton, 2001; Yin R. , 2009). This mixed methods study included diagnostic tests, student interviews, student notebooks, content quizzes, student essays, the instructor's written reflections, and more. Triangulation of the data provided reinforcement for certain tentatively identified patterns in the data, as well as showing that other patterns appeared inconsistently across methods or respondents.

Significant time was spent reviewing relevant literature before and during the study. The literature provided guidance and affirmation for the methodology selected for the study, as well as a foundation for understanding the resulting data.

Throughout preparation, implementation, and follow-up, my committee provided considerable insights and feedback. Committee members included experts and practitioners in both educational psychology and science education. Before the study, members read drafts of early chapters and provided suggested revisions. During data collection, two members met with me via phone every week to monitor methodology and to provide suggestions for improving data quality and implementation of instructional strategies. By providing the advisors with a summary of the past week and anticipation

for the upcoming week, these advisors were able to suggest adjustments to the study while in progress. On their advice, additional interviews were added to the study, interview questions were revised, student essays on topics aligned with the study were included, and more.

Working with a research assistant helped with quality as well. This allowed two people to code student responses, at first together and later independently to compare findings. The research assistant also provided insights by conducting informal classroom observations. During student interviews, she became a sounding board to discuss interview results and insights. After data collection, a draft of the results was sent to the research assistant for feedback and verification.

Limitations

Although the efforts above were taken to ensure the quality of this case study, I recognize that there were certain limitations in both scope and validity, particularly with respect to data collection, data interpretation, and transferring the interpretations to other classes or instructors. This section will identify some of these limitations; however, recognizing these limitations does not negate the value of pursuing practical research in the classroom environment.

To begin, the scope of this case study was defined by specific parameters. The study took place in one classroom with one instructor and a particular group of participants. Although Phases 1-3 contributed to the design, all data for this intervention was collected during the fall semester of 2011. Without a control classroom, results are

descriptive and based on student data from one class and my interpretation of that data, albeit with input from committee members and a student research assistant.

The validity of this study depended upon quality data collection tools. To keep the study practical, efforts were made to keep formative assessment data collection replicable in other elementary science methods classrooms. However, these practical efforts may have limited the variety and number of data collection tools used. Some tools, like the STEBI-B, have been verified and have a history of successful use in science education research. Other tools, like the formative assessment probes, were designed for instructional purposes, not for research.

Validity can be defined at the most basic level as the degree to which the descriptions and interpretations in this account are correct (Maxwell 2005). This correctness is dependent upon collecting accurate data. Measuring preservice teacher understanding and efficacy is complicated. In recording and presenting the results, I have tried to present a fair representation of student quotes and comments, without misrepresenting the students' voice to present my own personal biases. However, I must recognize that student comments in interviews and final essays may have been skewed to express what I wanted to hear instead of their true feelings. I also recognize my limited experience in conducting interviews and in collecting formative assessment data. Likewise, my research assistant was an undergraduate student without research experience who was relied upon to conduct interviews and classroom observations. Finally, although a variety of data methods and sources were used, this variety could not completely express the complexity or depth of student understanding or teaching efficacy.

Conducting the study within a classroom context necessitated a tension between research and instruction. This complexity may have provided limitations on data interpretation. As the instructor and researcher, I interpreted the formative data for the purpose of guiding my instruction while also collecting and interpreting data for this case study description. In addition, while the intent of the study was to examine the influence of formative assessment in the classroom, other factors could certainly have influenced students' understanding outside the classroom. Changes attributed to formative assessment could have been the result of student research, concurrent science or education courses, or a variety of external factors. In addition, my lack of experience in the area of coding and interpreting research data could have been a limitation as well.

Summary of Methods

The methodology described in Chapter 3 strove to coordinate practical instruction in the elementary science methods classroom with the collection and interpretation of data to answer specific research questions. Recognizing the context of the study, decisions were based upon related literature and lessons learned in Phases 1-3. Every effort was made to collect sound data and analyze that data so readers could consider the results and determine their transferability to other methods classrooms. The next chapter provides an account of the case study, including the data collected, and an analysis of the results in accordance with the research questions of the study.

CHAPTER 4

RESULTS

This study examined science methods course design, with the goal of improving preservice elementary teachers' understanding of science content and formative assessment. In this chapter we will begin with a look at the evolving course design as formative assessment is implemented into the elementary science methods course to improve science content understanding. Second, examining the findings collected during and after the intervention, I will explore student understanding to determine the results of the study with respect to each research question.

Collecting and using formative assessment data within the intervention causes some confusion as to whether the formative data results should be included with methods or results. A reasonable case can be made for either approach. I have chosen to include all formative assessment data here in Chapter 4, as in this study the intervention and formative results are closely intertwined. We begin this chapter with a case study description of how the formative assessment data was used to guide instruction in my elementary science methods course. Afterwards, each research question is addressed in light of relevant data from the formative assessments and other data sources. Data sources included student work, student interviews, science notebooks, surveys, reflections of my research assistant, and my own reflections.

Incorporating Formative Assessment within the Methods Class

This section describes the process and use of formative assessment used in the design of the study within the methods classroom. The first section explains how the diagnostic survey was used to select two science content topics. Afterwards, each topic is briefly presented, followed by a short explanation of formative assessment practices used for that topic. Assessment tools used during the course included a diagnostic survey, formative assessment probes (Keeley, 2011), group concept maps, a non-graded quiz, student science notebook entries, a pretest, and student reflections. The sequences presented in Table 3.1 and 4.1 were used during the actual instruction. Each formative tool provided unique insights into student understanding which was then used to guide instruction. Descriptions of my instructional applications are included in each section.

Table 4.1 Summary of Formative Assessment Tools Used During the Course of the Study

Formative Assessment Tool	Information provided	Types of decisions influenced
Diagnostic Survey	Student science content knowledge	Used to determine science content topics for the study
Science Notebooks	Record of learning about science content & formative assessment through concept maps, drawings, definitions, reflections and more	Guided curriculum decisions, lesson design, and teacher feedback
Formative Assessment Probes	Pervasiveness of specific science misconceptions	Guided curriculum decisions, topics to discuss and time spent on topics. Helped students compare their responses with peers.
Concept Maps	Small groups content knowledge and questions raised about the science topic	Guided decisions about science content instruction

Table 4.1 Continued.

Non-graded Quiz	Individual student's knowledge and questions about the science topic	Guided instructional decision. Provided students with insights into their own understanding.
Pre-test	Knowledge of science content	Confirmed level of student background knowledge for second science topic. Guided curriculum and instructional decisions.

Selecting the Science Topics

To establish an authentic context for implementing formative assessment, I needed to identify specific science topics to address in the methods class. I used a diagnostic survey (American Association for the Advancement of Science, 2011) to determine which science topics were least understood among the students in this class, enabling me to focus the instruction on supporting student learning of such topics through cycles of formative assessment and instructional adaptation. There were three layers of analysis to determine which topics to study. First, I identified the questions on which more than half of the students chose incorrect answers (14 of the questions). The second layer of analysis was to compare the field test results from the AAAS website (American Association for the Advancement of Science, 2011) for each question with the answers provided by the students in the class (seven of the questions). The third analysis looked to see if multiple questions identified above were from the same science topic. In the end, two topics met all of the following three criteria: (1) most of the students missed the questions, (2) multiple questions in the topic were missed, and (3) the class scored considerably lower than the national field tests for those questions (see Table 4.2). The two topics were plate tectonics (PT) and matter and energy in living things (ME). The

specific questions related to matter and energy in living things dealt with energy in plants, specifically plant food. Therefore, the science content of the six week study became three weeks of plant food and energy, followed by three weeks of plate tectonics.

Table 4.2. Item Analysis of AAAS Diagnostic Survey Results to Explore Science Content Understanding of Students in the Science Methods Class.

Question Number	Students performed		Student responses were mostly CORRECT or mostly INCORRECT	AAAS Science Topic
	BETTER than national average	SAME as national average		
1		BETTER	CORRECT	AM
2		SAME	INCORRECT	AM
3		BETTER	CORRECT	AM
4		BETTER	CORRECT	AM
5		BETTER	CORRECT	AM
6		SAME	INCORRECT	AM
7		SAME	INCORRECT	AM
8		BETTER	CORRECT	AM
9		BETTER	CORRECT	CV
10		BETTER	CORRECT	BF
11		BETTER	CORRECT	BF
12		BETTER	CORRECT	BF
13		BETTER	CORRECT	CE
14		BETTER	INCORRECT	CE
15		BETTER	CORRECT	CE
16		BETTER	CORRECT	CV
17		SAME	INCORRECT	EN
18		BETTER	CORRECT	CV
19		SAME	INCORRECT	FM
20		BETTER	INCORRECT	FM
21		BETTER	CORRECT	FM
22		BETTER	CORRECT	MO
23		WORSE	INCORRECT	IE
24		BETTER	CORRECT	IE
25		WORSE	INCORRECT	ME
26		WORSE	INCORRECT	ME
27		WORSE	INCORRECT	ME
28		BETTER	CORRECT	ME
29		BETTER	CORRECT	MO

Table 4.2 Continued.

30	BETTER	CORRECT	NG
31	BETTER	CORRECT	NG
32	BETTER	CORRECT	PT
33	WORSE	INCORRECT	PT
34	BETTER	CORRECT	RH
35	WORSE	INCORRECT	PT
36	BETTER	CORRECT	RH
37	BETTER	CORRECT	SC
38	BETTER	CORRECT	SC
39	BETTER	CORRECT	WE
40	WORSE	INCORRECT	WE

Note: Each of the actual content topics can be identified at the AAAS website <http://assessment.aaas.org/pages/home> under the topics tab.

Integrating Formative Assessment with Topic 1: Plant Food and Energy

Establishing the Content Parameters for Topic 1 The first topic to teach was plant food and energy which included plant food and the process of photosynthesis. As I prepared to teach this topic, I identified the content parameters and expected to present certain information. However, as I utilized formative assessment, building on the preliminary information gleaned from the Diagnostic Survey, I continued to add content material that appeared to be missing from student understanding. This comparison between my expected content parameters, and the eventual extent of the content introduced, is shown in the concept map below (Figure 4.1). The central concept was plant food and energy. The white ovals show my initial content expectations, and the shaded objects indicate the material added to the course as I utilized formative assessment to guide instruction.

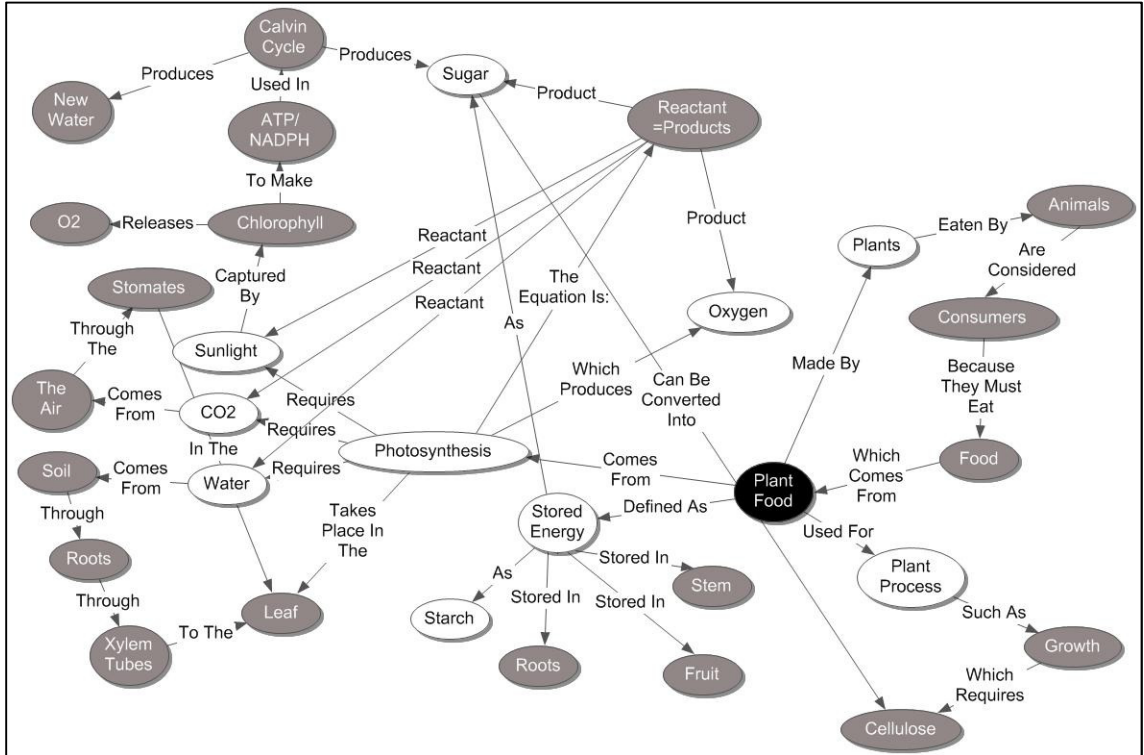


Figure 4.1. Topic 1 concept map. Concept map designed to compare initial content (white) to added content (shaded) as a result of using formative assessment to guide instruction.

Monitoring Student Understanding and Fostering Communication about Topic 1 Throughout our study of Plant Food and

Energy, the students continued to use the science notebooks they were given at the beginning of the course, and I continued to collect the notebooks for formative assessment and to provide feedback. The variety of assignments and entries in the notebooks allowed me to explore different aspects of any student's learning throughout the unit. For instance, before any instruction on Topic 1, students were asked to draw and explain a model of photosynthesis in their notebooks. The entries provided insights for me to see their prior knowledge about photosynthesis and provided students with a picture of their initial limited understanding that they could look back on later. Later in

this unit, another entry asked students to draw a concept map for plant food. After collecting the notebooks, I learned that students struggled with understanding plant food and with designing concept maps. Data from these and other entries was used to address specific research questions later in this chapter.

Uncovering Student Ideas about Topic 1 I was able to find numerous formative assessment probes related to food and energy in living things, and chose two for use at the start of our unit on Plant Food and Energy. On the first day of the intervention, students were given two probes; one was entitled “Is it Food?” (Keeley & Tugel, 2009) and the second was “Chlorophyll” (Keeley, 2011). The food probe (Appendix A) listed a variety of items consumed by people and asked students to check off the items that are scientifically called food. Students were also asked to provide an explanation for their answers. As can be seen in Table 4.3, only three students explained that food was something our body can break down (or digest) to provide energy. For instance one student wrote, “In order to decide what was and was not food from the list I defined food as something that our body can take and break down to provide energy for the consumer.” Although this is correct, she went on to say, “It is something that can be eaten alone or is natural and does not contain preservatives. This is why ketchup and butter are not in the list because they have added preservatives to them. Water and diet soda are a drink. Not food.” The probe specifically asked, “What definition or ‘rule’ did you use to decide if something can scientifically be called food?” (Keeley & Tugel, 2009, p. 91). The desired response should recognize using any organic substance for energy.

Almost every student used common language definitions such as “a liquid is not food” or “an ingredient is not food” to make their decisions.

The Chlorophyll probe asked students to pick which items on a list were functions of chlorophyll and then asked to explain their thinking. The results showed that most students realized chlorophyll provides the plants with green color (90%) and chlorophyll somehow absorbs light energy (80%). Some of the incorrect functions of chlorophyll selected by students were: a storage product (50%), a source of food (45%), absorbing carbon dioxide (40%), breaking down sugar and starches (50%), and manufacturing food (55%). Given the design of this particular probe, it was impossible to identify whether the students were just guessing, or if they actually held those misconceptions. Providing students with choices helps them to commit to an answer, but without explanations, it is difficult to know why they chose a particular answer. On the flip side, simply asking students to explain the function of chlorophyll does not guarantee sufficient data to guide subsequent instruction.

Table 4.3. Results of the Formative Assessment Probe “Is It Food?”

Generally considered food	Number of yes checks	Generally not considered food	Number of yes checks
Banana	19	Milk	4
Turkey	19	Ketchup	4
Lettuce	19	Sugar	4
Bread	18	Syrup	4
French fries	16	Butter	4
Cookies	16	Flour	4
Candy bar	15	Vitamins	3
		Minerals	3
		Salt	2
		Water	2
		Diet Soda	0

Table 4.3 Continued.

Students' rules for deciding if an item is scientifically called food	Number of students
Not a liquid (or drink)	11
Can be eaten alone	10
Can chew on	4
Not ingredients	3
Not vitamins or minerals	3
Something our body can break down for energy	3
Healthy	3

Note: N=20

Guided by the data from the probes, I realized that many of the students defined food by how it was obtained. I wanted students to accept a scientific definition of food as an organic molecule of stored energy; made by plants, and utilized by both plants and animals. Therefore, I decided to emphasize the connection between plant food and human food. I visited with a biology professor at my campus to confirm my own understanding and to learn the relationship between glucose and cellulose in plants. The goal for the informative lesson on Friday was to provide a scientific understanding of food and to make a connection between the food we eat and the food that plants produce. A second goal was to outline the reactants and products of photosynthesis. During Friday's lesson, students' familiarity with the terms consumer and producer helped to reinforce the food connection between plants and animals. At the end of the lesson, I asked for questions and was surprised that there were none. I shared that as a teacher, my assumption could be that the students all understood plant food and photosynthesis. However, I also emphasized that formative assessment provided tools to help me explore what misunderstandings they may be unaware of.

As I approached the second week, I wanted to identify which aspects of Plant Food and Energy should be the focus of the next lesson. Appreciating the guidance from the previous week's probes, I decided to begin with two more formative assessment probes. One probe addressed where food was made in an apple tree (Appendix A) and the second considered the processes of photosynthesis and respiration in plants in the light versus the dark (Keeley, 2011). For both probes, students needed to choose a statement they agreed with and explain their decision. On these probes, most students identified the correct scientific statement (Tables 4.4 and 4.5) and provided accurate explanations. With most students showing a correct understanding, I decided the goal for Friday's lesson would be to answer student questions relating to photosynthesis. To do so, I tried a different type of formative assessment on Wednesday: using concept maps (White & Gunstone, 1992) with the intent of using the mapping to generate student questions.

Table 4.4. Results of Formative Assessment Probe "Light and Dark"

Light and Dark Probe Statements	Students who agree
Student chose the statement they agreed with the most	
P occurs when it is light; R occurs when it is light and when it is dark	18
P occurs when it is light; R occurs when it is dark	3
P occurs when it is light, plants don't carry out the process of R	1
P & R occur both when it is light and when it is dark	1
P occurs both when it is light and when it is dark; R happens at night	0
Student responses -Explain why you agree with that statement and not the others	
Photosynthesis needs light	20
Respiration can occur whenever	14
Photosynthesis occurs in both light and dark	1

Note: In the Light and Dark probe statements, P=photosynthesis and R=respiration. N=22.

Table 4.5. Results of Formative Assessment Probe “Apple Tree”

Apple Tree Probe Statements	Students who agree
Which do you agree with the most?	
I think the food is made in the leaves of the tree	17
I think the food is made in the tree’s roots	4
I think food is made in tiny tubes in the trunk and the branches	3
I think food is made in the apples the tree produces	2
I think food is made in the apple blossoms	0
I don’t think apple trees make their own food	0
<u>Explain why you agree – many left blank, some comments below</u>	
Chlorophyll is in the leaves	1
Stored in the fruit	1
Apple is the food	1
Roots work together to make the food	1
Food is from tiny tubes	1

N=24. Two students agreed with two statements.

Generating Student Questions A common experience during the intervention was to ask for questions during and at the end of a presentation. The students in my class did not like to ask questions in front of the class. The assessment probes for week two indicated considerable student understanding about when and where plant food is made (Table 4.4 and 4.5), so I followed up by asking each student to draw a concept map about plant food in his or her science notebook. My reasoning was that the students already understood the specific material I had planned to teach, therefore I wanted them to step back to see if they could connect their pieces of knowledge into a coherent concept map. Looking at their concept maps, most (75%) of them had less than ten items, and very few included arrows or connections between objects (Figure 4.2 shows a typical example).

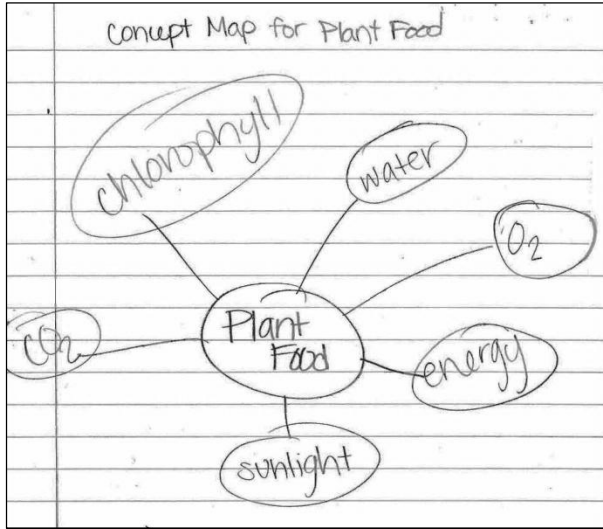


Figure 4.2. Initial concept map. Typical student's first attempts at a concept map for plant food.

These maps revealed limitations of student understanding that were completely missed by the earlier probes. Without further data, it was impossible for me to know if students had limited knowledge about the production of food in plants or limited concept mapping skills. I realized that if concept maps were to be useful as a formative assessment tool in the course, then students needed guidance for creating concept maps that accurately represented their knowledge of a particular topic.

My initial plan had been to have groups of students submit questions during class on Wednesday of week two, but I changed plans after looking at the concept maps in their notebooks and discussing these with the two faculty advisors serving as sounding boards during this phase. I recognized that designing maps in small groups could become a helpful tool for generating the students' questions.

I addressed this during Wednesday's class by listing all the terms students could relate to the concept of density on the whiteboard (based upon a previous inquiry experience) and then I demonstrated how to incorporate every single term into a concept map using a think aloud process. With this demonstration fresh in their minds, students gathered in small groups to process their collective understanding of photosynthesis, to draw group concept maps (Figure 4.3) and to generate three to five questions about photosynthesis that came up during the mapping activity. The group questions were turned in with the concept map at the end of the class.

Creating group concept maps (Figure 4.3) was used to generate student questions which were then used to guide Friday's lesson on photosynthesis for week two. Therefore, the combined use of concept maps and student questions became the formative assessment tool. After class, one student commented, "I think students like being able to turn in anonymous questions; it frees them up so they can ask without being scared". A partial list of the students' questions is listed in Figure 4.4 with a complete listing in Appendix E. The list of questions in Figure 4.4 was generated following week one's lesson on plant food that included drawing notes on leaves, discussing food and photosynthesis, and an online simulation to show the comparative size of a plant cell. The questions turned in demonstrated that students knew much of the vocabulary, but demonstrated less evidence of their ability to connect the information together. The group concept maps also showed improvement in students' ability to design concept maps (comparing Figures 4.2 and 4.3); although the comparison is imperfect since the initial concept maps were created by individuals and the later ones by teams of students.

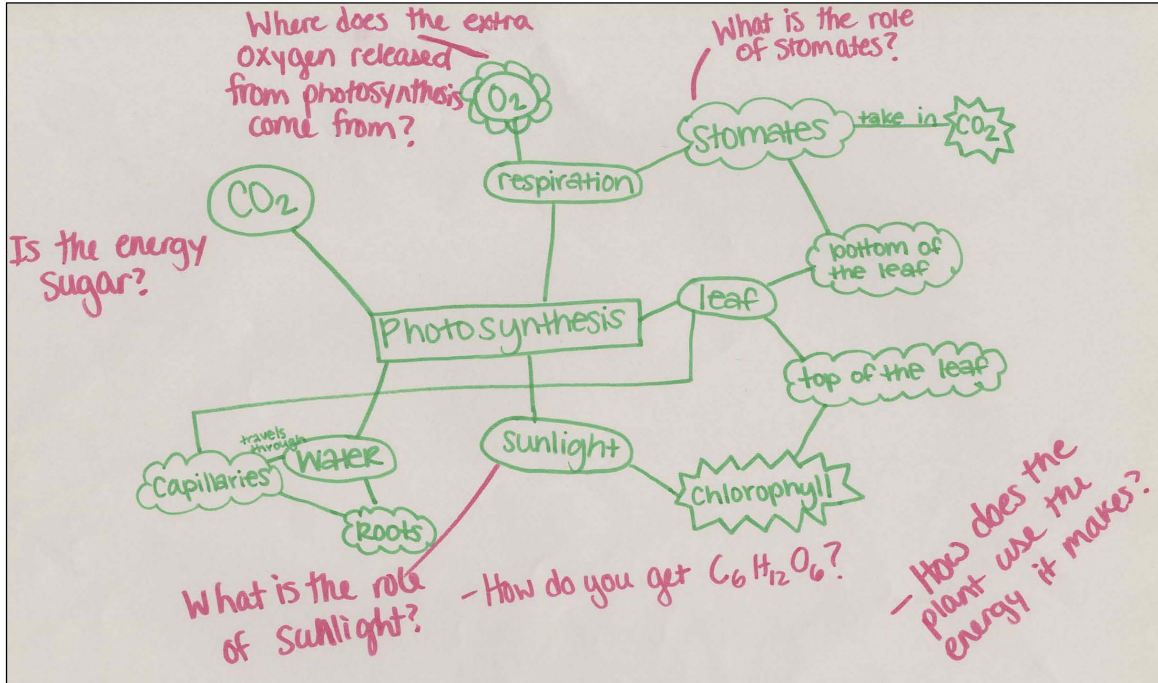


Figure 4.3. A group concept map with student questions.

After reading this list, I determined that students needed an engaging, memorable, overview experience with photosynthesis on Friday. They needed to see the complete process, beginning with water and carbon dioxide entering the leaf and ending with sugar exiting the leaf. This challenge developed into a dramatic portrayal of photosynthesis with students performing prescribed roles and others standing on chairs to visualize the entire process. The students took turns acting and watching, while I was able to freeze the drama to explain each step of the process and to answer student questions.

Questions about Chlorophyll and Light

- What is chlorophyll?
- Can a plant have a different source of light?
- What else does chlorophyll do?
- Why do the leaves make a green color?
- Can you check how much chlorophyll is in a leaf?
- Does the amount of chlorophyll affect the color of the leaf?
- What is the role of sunlight?
- How does sunlight become energy?
- Where does the energy come from?
- How does chlorophyll relate to energy and sunlight?

Questions about how the Plant Obtains Material for Photosynthesis

- Where does the extra oxygen released from photosynthesis come from?
- What is the role of stomata?
- How is CO₂ caught?
- What part of the leaf does the CO₂ come from?
- Does the soil play a part in the process of photosynthesis?
- If you water a plant with something other than water, what happens?

Figure 4.4. A partial list of student questions generated from creating group concept maps about photosynthesis.

Students Identify Gaps in their Understanding On Monday of the third week, the students were given a non-graded quiz on photosynthesis. The quiz was designed to help each student compare his or her understanding with my learning goals for photosynthesis and plant food. The quiz questions were displayed on the SMART board and students were asked to write their answers in their science notebooks. Similarly to the exercise with group concept maps, students were asked to write specific questions or areas of confusion to address in class on Friday. I collected the notebooks and compiled the questions as listed in Appendix F. A partial list is included in Figure 4.5.

How do the items for Photosynthesis get to chloroplasts?
 How photosynthesis gets to chloroplasts.
 How do the items needed for photosynthesis get to the chloroplasts?
 What was being changed by chlorophyll?
 What is the chlorophyll charging exactly? ADP? APP?
 What is chlorophyll?
 What happens after water is broken apart in the chloroplasts?
 How does the Oxygen get charged in the light reaction? (Unclear question for me)
 What is the relationship between chlorophyll and chloroplasts? Is all of that found in the cell?
 Chlorophyll – not sure if I have the right definition.
 Plant parts
 Why the substances make things?
 How do capillaries transport and give away water?
 Roots, what do they do?

Figure 4.5. A sample of student questions generated from a non-graded quiz. The complete list is available in Appendix F.

There was a difference in student questions generated from concept maps (Figure 4.4) and those generated from the non-graded quiz (Figure 4.5). The questions from the concept maps were more varied and general, which gave a great insight into students' wonderings about the topic. I think generating the questions helped students connect with the material and increased engagement. However, it was difficult to focus instruction from those questions. The student questions from the non-graded quiz (Figure 4.5) were more specific and applied directly to the learning goals of the unit. This helped me to design the next lesson in response to their questions and moving the entire class towards the learning goals.

Looking over this list of questions (Figure 4.5) helped me to recognize three aspects of my students' learning. First, the specificity of the questions indicated students' engagement with the material. Instead of "I don't understand the role of chlorophyll",

students were asking, “What is the chlorophyll charging exactly? ADP?” and “What is the relationship between chlorophyll and chloroplasts?” This demonstrated that students were already thinking about the concepts and might be more receptive to the answer than if it was just included in notes for the class. Second, it was encouraging to see questions that had nothing to do with the quiz. This demonstrated that students were thinking about the process and had identified holes in their understanding. Examples include, “Roots, what do they do?” and “How long does the process of photosynthesis take?” Third, as I showed this list to the class on Friday, they could see their questions in the list. The questions on the list provided the organization for my lesson. Throughout the lesson, I pointed to questions, showing them how the formative data was guiding instruction. At the end of the lesson, I asked for any further questions or clarifications. No questions were asked. In hindsight, I should have asked them to write two things they learned and one unanswered question as a ticket out the door. That was the end of instruction on plant energy and photosynthesis, the next topic was plate tectonics.

Integrating Formative Assessment with Topic 2: Plate Tectonics

Establishing the Content Parameters for Topic 2 The second topic of study was plate tectonics. As shown earlier with plant food and energy, the content presented in the class expanded with students’ questions and with formative assessment data. The concept map (Figure 4.6) shows the initial content (white ovals) and the additional content (shaded ovals) included in the lessons on plate tectonics. The state standard that relates to plate tectonics is for middle school and states that students should “understand

and demonstrate knowledge of the structure of the earth system and the processes that change the earth and its surface” (Iowa Department of Education, 2011). This standard led to my initial three content goals that students would 1) understand what plate tectonics were (including the three boundary types), 2) recognize the explanatory usefulness for earthquakes and volcanoes, and 3) recognize the historical process of the theory’s acceptance. The shaded ovals (Figure 4.6) show material that was added because of resources included in lessons or questions from students. For instance, when I decided to modify a middle school pretest to use with my students, I added the science targets from the pretest to the course content. Initially, I was going to include Pangaea and models of plate movement over time (relating to a different state standard). Realizing that I tried to include too much material in the plant food and energy unit, I remained committed to the more foundational of the two plate tectonics-related standards and did not add discussion of Pangaea to the content lessons.

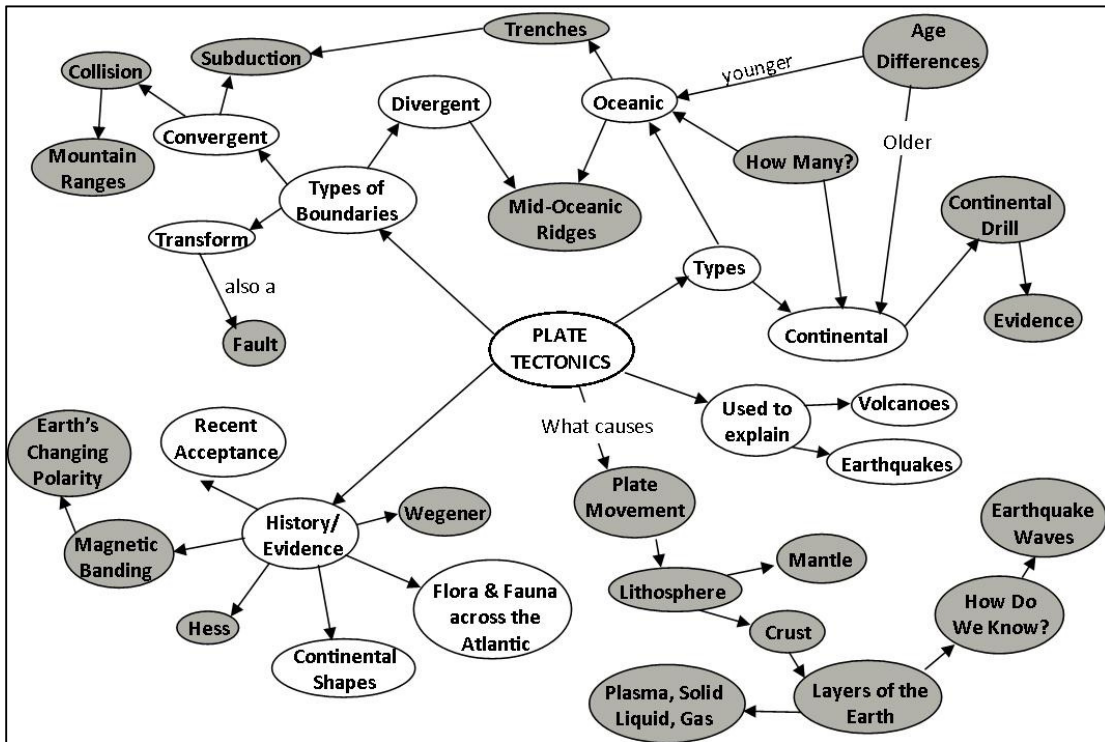


Figure 4.6. Topic 2 concept map. The content included in the plate tectonic lessons.

With only three weeks to teach plate tectonics, it was necessary to design a learning sequence to help pace the lessons. Using the 5E lesson design (Bybee, 1997), I tried to include learning experiences that would engage students, involve student exploration, explain key points, elaborate understanding, and evaluate learning. The first lesson introduced plate tectonics, engaged student interest, and provided an overview of the unit. Topics covered included history of the theory, examples of volcanoes and earthquakes, and identifying plate boundaries on a map. Between the first two lessons, students were given an online exploration assignment explained in the section below entitled Student Exploration and Reflection. The second lesson needed to explain plate boundaries, layers of the earth, and details of a subduction zone. The final lesson

addressed the source of plate motion and included time to elaborate on students' questions. The learning sequence can be visualized in Figure 4.7.

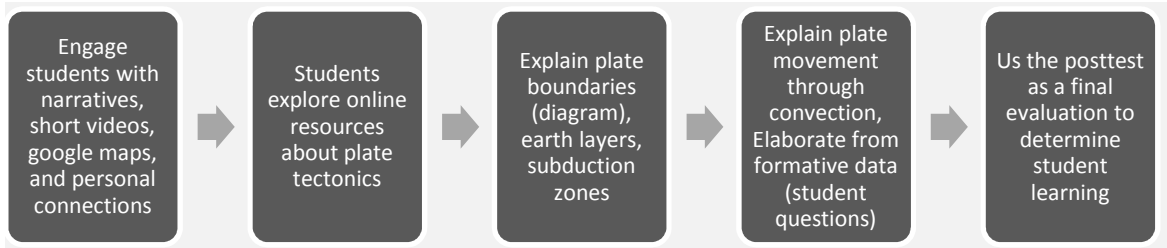


Figure 4.7. Learning sequence for the three weeks on plate tectonics.

Uncovering Student Ideas about Plate Tectonics Based upon conversations with students, it sounded like most students knew very little about plate tectonics. I decided to gather data to verify this. Modifying a quiz for middle school students (Sostarics, 2011), a pretest was given on Monday of the first week. Students were told to leave a question blank instead of guessing. The results confirmed that they knew very little about plate tectonics. Of the 21 possible points on the quiz, the average score was 2.3 points with a range of zero correct (five students) to eleven correct (one student) ($N=24$). There were more blanks than answers on the pretest.

This formative tool clearly identified that students had missing or incomplete knowledge when it came to understanding and demonstrating knowledge of “the structure of the earth system and the processes that change the earth and its surface” (Iowa Department of Education, 2011). My task for Friday was to introduce the topic so that students were eager and interested in learning more. For some reason, most students had not been taught about the topic (the local school system only teaches it in 8th grade). It could be that people in Iowa feel removed from the realities of plate tectonics. Iowa was one of four states with no reported earthquakes from 1975-1995 (U.S. Geological

Survey, 2011). I also wondered if the Christian background of my students had caused them to disregard plate tectonics as conflicting with Biblical Creationism.

Responding to the students' initial ideas about plate tectonics, I designed Friday's lesson to include student-paired conversations about Wegener and Hess readings (Williams, Clough, Dawson, & Cervato, n.d.), short videos on earthquakes and volcanoes, and a discussion about faith and geology. Here are my reflective notes written after Friday's lesson

As I considered teaching plate tectonics, I wondered what emotional appeal plate tectonics could hold for students in Iowa. I considered the conflict of some who may hold a young earth concept of Creation. With this in mind, I started the class with students sharing the story of Wegener [half the class] with someone who read Hess [other half of the class] and vice versa. This forced them to engage in the concept and wrestle with the concept as well as recognizing the process of scientific acceptance. After that, we talked about faith and science... My second method of emotional connection involved showing a couple of video clips –one of earthquakes, one of a recent volcano, and Google maps. Weather.com had a video of a fantastic eruption only 4 days old. This was an awesome present-day example that volcanoes are not only in the past, but they happen right now – 4 days ago. During class I shared that we don't live in fear of volcanoes and earthquakes here in Iowa. Why not? Does the model of plate tectonics give us confidence that our class won't be interrupted by an earthquake (as seen on the video) or a volcano suddenly appearing on the green? (Brower reflection, November 11, 2011)

Concerning faith issues, some students had not considered any conflicts. Others shared how they had reconciled the conflict between young earth and old earth worldviews.

Students shared and articulated faith challenges and resolutions with each other.

Compared to photosynthesis, students sounded more curious and eager to learn about plate tectonics. This was evident through the questions asked during class and

substantiated through the student interviews. One student's comment on her final essay

said, “I felt as though I was intrinsically motivated to understand the topic and this also sparked interest in the topic at hand. I feel as though I have a very good understanding of plate tectonics and this is due to the way formative assessment was used.”

Student Exploration and Reflection Preparing for the second week of plate tectonics, I felt that the students did not yet have enough content knowledge to justify probing their understanding with another formative assessment tool. Recognizing their limited knowledge from the pretest, students were asked to explore websites designed to increase educators’ understanding in plate tectonics. I told them to imagine that they needed to teach a unit on plate tectonics and this was an opportunity to improve their understanding prior to designing the unit. The four sites I posted for students to begin their exploration included the Digital Library for Earth Systems Education (National Science Digital Library, 2011), a NSTA page of teaching resources on earthquakes and tsunamis (Brunsell, 2011), an online version of *This dynamic earth: The story of plate tectonics* (Kiouss & Tilling, 2011), and a plate tectonics overview posted by the Hartebeesthoek Radio Astronomy Observatory (2011). My hope was that the assignment would model the self-initiated learning that all teachers do as they prepare to teach a new topic. In their science notebooks, students recorded summaries of their learning and reflected on how they could use the websites in their own teaching. Entries varied as most students listed new information they learned about plate tectonics, a smaller number focused on finding teaching resources as illustrated in the following entry

Learn 360 – Shaping Our Planet

Grades:Pre-K-2

I really liked this clip because it was in a language that young students would understand. It basically just quickly explained ways in which the

land masses change on Earth – erosion and plate tectonic movements. It was short enough for students to receive important info but not get bored with it being too long. I would probably show it as an introduction to plate tectonics. (Student Notebook)

As an exploration activity, I was comfortable with the variety of student experiences and their interpretations of the assignment. If I were to restructure or enrich the assignment, I would discuss the initial results in class, and then require students to prepare a report about the instructional value and potential applications of the resources reviewed to share with an audience of elementary teachers.

The lesson on Friday included a variety of instructional activities. The lesson began with students working with a partner through a lecture tutorial on plate boundaries (Kortz & Smay, 2010). Next, students engaged in an edible tectonics activity (Ford, 2001) in which students cracked open candy bars and looked at the layers within, discussing the different textures and relationships between asthenosphere, crust and mantle. After that, using diagrams and short videos, I tried to provide clear explanations on the three different types of plate boundaries, especially subduction zones.

Student Initiated Formative Assessment During the last week of the study, students read chapter 9, “Assessment for Learning”, in their text (Harlen, 2001). My goal was that students would strengthen connections between their classroom experiences and the author’s examples, purposes and values for using formative assessment to improve student learning in the classroom. After a class discussion on formative assessment, students formed small groups. Anticipating an upcoming content quiz to measure improved understanding of plate tectonics (summative assessment), student

groups were tasked with determining the best formative assessment tools to guide Friday's final lesson on plate tectonics. The groups' suggestions were:

- The instructor needs to present instructional learning goals for the final quiz
- Students produce concept maps as groups or individuals to determine questions
- Instructor could design review game and also require each student to record all answers for each question.
- Students produce a short written summary in their science notebooks with questions they still had on plate tectonics.

In response to their suggestions, I presented my instructional learning goals for plate tectonics. Next, working with a partner or as an individual, students were given time to choose a formative tool to use (such as a concept map or writing a summary) and to provide me with useful data (questions or topics to address) to guide the final plate tectonics lesson on Friday.

On Friday, students were shown their data organized into the eight categories shown in Appendix G. Figure 4.8 shows one category. Repeated topics in the list, like subduction and volcanoes, conveyed that multiple student groups (or individuals) submitted that topic. Students could see how formative data provided guidance by focusing my elaborations on the topic and helping them prepare for the final quiz. For example, in Figure 4.8, the repetition within the formative data showed me that subduction and volcano formation needed to be elaborated upon, while the formation of trenches did not. With only one question about trenches, I made an evidence-based instructional decision to spend more time elaborating on volcanoes and less time on

trenches. Using the data, I showed students why I made this decision and then my instruction demonstrated it.

<p><u>Convergent-volcanoes-subduction</u> Two types of convergent boundaries Explain stars and square diagram Subduction probe answers Explain subduction diagram from probe Subduction What forms a trench? Where does the plate go after subduction? Is the plate gone forever? What causes volcanoes? Subduction and volcanoes Subduction and volcanoes Do only divergent plates cause volcanoes? Divergent plates and volcanoes</p>
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Figure 4.8. One category of student generated items to include in the final instruction on plate tectonics.

Summary of Formative Assessment Implementation within the Methods Class

The results presented so far show how the course design allowed for formative assessment to influence instruction and student learning throughout the six weeks of the study. Sometimes raw data, like the formative assessment probes and the unit pretest, provided immediate insights into student understanding for a specific content area. Other formative tools, like teacher feedback in science notebooks or a non-graded content quiz, provided students with insights into their own understanding. Another useful application of formative assessment was to use a self-analysis tool like concept mapping, to facilitate the generation of student questions, which then could be used to guide instruction.

In keeping with the design experiment, lessons learned during unit one could be used to improve the effectiveness of unit two. The first topic, plant food and energy,

provided almost unlimited related topics to explore. As specific areas of incomplete student knowledge regarding the first topic were identified, I was able to target where to provide additional instruction. Realizing that instructional time is limited in all learning environments, I limited the content included in the second topic by committing to only one of two relevant standards, choosing the most foundational one. After the first unit, I wondered how much students had learned about plant food and energy. With this in mind, I began the unit on plate tectonics with a pretest to reveal student prior knowledge that could be compared to a posttest at the end of the course to measure improved understanding.

Initially, I felt that it was my responsibility to determine which formative tools to use and to anticipate how they would be used to guide instruction. However, as the preservice teachers gained experience and understanding, they provided insights and suggestions. The last week of the study I presented students with the opportunity to choose their preferences. They responded by asking for clear learning goals and then using formative tools to provide specific questions to guide the last instructional lesson on plate tectonics. The following sections will present additional data to address the four research questions of this study.

Changes in Student Understanding of Science Content and Formative Assessment

The first research question asked, Building on formative assessment data, how can science methods class instruction be designed and implemented to improve student understanding of science content and formative assessment? The design and implementation of the science methods class instruction using formative assessment has

been described above. In the first section that follows, I provide evidence of students' increased science content understanding; in the second, evidence of increased understanding of formative assessment.

Science Content Understanding

During the course of the study, students increased their understanding of plant energy/photosynthesis and plate tectonics. Student understanding of the science content was measured using pre and post diagnostic comparisons, pre and posttests, and pre and post student interviews.

Pre/Post Diagnostic Comparisons The first piece of evidence used to demonstrate student understanding was the diagnostic survey. Initially, the diagnostic survey was used to determine the two science content topics. At the final exam, a shortened version of the diagnostic survey was given to students. With limited time available, the survey was reduced to nine questions including all of those pertaining to plant food/energy and plate tectonics. Pre and post results for the percentage of correct answers attained by students are shown in Figure 4.9. For example, on question 25, the pre-study survey showed that 12.5% of the students chose the correct answer. In the post-study survey, 75% of the students chose the correct answer for the same question, a result that is much higher than the 39% of high school respondents answering correctly in the national field tests. The questions related to the two science topics in the study, plant energy and plate tectonics; show considerable improvement in the post-study survey. In addition, the post diagnostic survey results show that the percentage of correct responses for each of the

nine questions was now higher than the National field test results based on responses of American high school students (Figure 4.9).

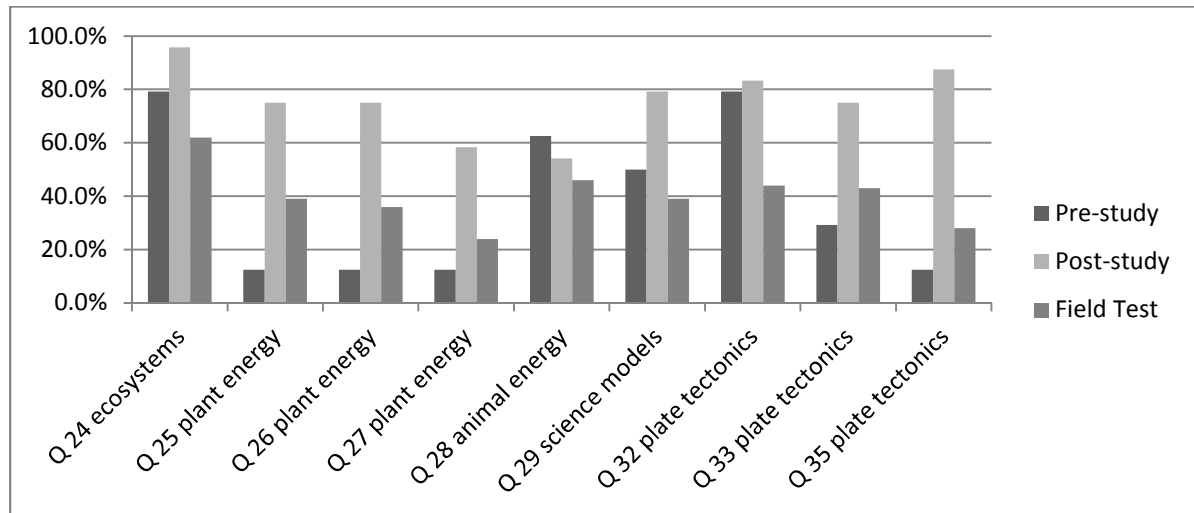


Figure 4.9. Comparison graph of the percentage of correct student responses to diagnostic questions before the study, after the study, and the National field test results (American Association for the Advancement of Science, 2011). $N=24$.

Pre and Posttest Based upon the diagnostic survey and student interviews, plate tectonics was not well known among the students in the class. One student mentioned in her interview that she had “no recollection of ever learning about plate tectonics”. With this limited student knowledge, I modified a middle school Earth Science pretest to provide additional baseline data on student understanding (Sostarics, 2011). When given the pretest (Appendix J), students were asked to leave a question blank if they did not know the answer (as opposed to guessing). The pretest included two questions about Pangaea which I did not discuss in the lessons so those questions were not included in the posttest. Comparing the repeated questions, the average student score ($M=1.6$, $SD=1.6$) showed remarkable and statistically significant improvement in the posttest ($M=15.3$, $SD=2.3$), $t(23)=22.8$, $p<.001$, $d=5.93$. The pretest-posttest comparison demonstrates

increased learning in plate tectonics. However, without a control group, these results do not indicate that the content learning experiences paired with ongoing formative assessment in the course were responsible for this change in understanding.

A pretest was not given for plant food and energy. At the time, I had expected the assessment probes to provide clearer data on students' prior knowledge. Student explanations in response to the probes were not consistent or complete. The limitations of the formative probe data prompted me to use a non-graded quiz to help students self-identify areas that needed further instruction. The non-graded quiz results were entered in student notebooks followed by sharing responses with a partner and revisions, therefore the quiz results did not provide true initial understanding to compare with the final quiz. It did, however, solidify my decision to use a pretest for plate tectonics.

Student Interviews Interviews were conducted with seven students selected as a typical representation of the class (Table 4.6) to assess student understanding of both science content and formative assessment. The homogeneity of the students in the class is reflected in the frequency of white female, traditional, residential students from the Midwest United States. The 15-30 minute interviews included questions about student understanding of plant food/energy and plate tectonics and were conducted before, during, and after the study. Three of the students were interviewed by my undergraduate research assistant; who had taken the class previously, had been interviewed by me to test the interview guide questions, and met with me regularly to discuss improvements to the interview process. We took notes during the first round of interviews and wrote “facsimiles” (Stake, 1995), since audio-taping with transcriptions did not fit the intent to

model formative assessment techniques that are practical for a typical methods course or K-8 teacher. However, after discussion with my committee advisors, it became apparent that note-taking did not allow us to fully capture students' understanding, and thus the second and third interviews were taped and transcribed.

Table 4.6. Demographic Information for Interviewed Students

Student	Age	Gender	Ethnicity	Credit Load	GPA	Home location	Resident/Commuter
Helen	21	Female	White	17	3.6	Rural Midwest	Resident
Carrie	20	Female	White	16	3.5	Midwest City	Commuter
Kristen	20	Female	White	19	3.6	Rural Midwest	Resident
Clara	21	Female	White	17.5	3.5	Rural Midwest	Resident
Wendy	20	Female	White	18	2.9	Midwest City	Resident
Tracy	21	Female	White	19	2.7	Rural Midwest	Resident
Tara	21	Female	White	16	3.7	Midwest City	Resident

Note: Self-reported demographic information for the interviewed students. Names are pseudonyms.

During the initial interview, students were asked about the two science topics. Although students knew more about plant food than they did about plate tectonics, none of them provided an accurate definition of plant food (Table 4.7). As mentioned above, our raw data for the first interview consisted of notes and a facsimile, while audiotapes and transcriptions were available from the next two rounds. So, although we observed that students' initial interview responses were shorter, given the differences in how the interviews were recorded, definitive comparisons of the length and detail of students' explanations across all three interviews was not possible. In the second interview,

students were asked to reflect on how they thought their understanding improved, but were not asked specific content questions about plant food or photosynthesis. In the final interview, students were asked, “What is plant food and where does it come from?” which asks for more detail than the original question “what is plant food?” The student responses varied, but all final interview answers demonstrated fewer misconceptions, more detailed explanations, and emphasis on the process of food making, as shown in Table 4.7.

Although the increasingly detailed explanations students provided may be attributed in part to the use of transcription in later interviews, and the students’ increased emphasis on the process of food-making is probably partially due to the way the question was phrased, the reduction in misconceptions appears to be a result of the science instruction paired with formative assessment students experienced in the methods class.

The most correct answers in Table 4.7 are from students two, three, five, and six. Student four still shows the misconception that water and sunlight are plant food. Although student one does not answer the question “What is plant food?” and seems to lack confidence, she is able to explain the process of photosynthesis as she recounts the drama experience from the lesson. The final interview was conducted three weeks after the last lesson on plant food and approximately six weeks after the initial interview.

Table 4.7 Comparison of Initial and Final Student Interview Responses for Defining Plant Food.

Student	Initial definition. What is plant food?	Final definition. What is plant food? -Where does it come from?
1	Soil and fertilizer	Comes from oxygen and water...it's used in the rest of the plant...to keep producing the food...we did the whole acting out thing...so the water and the oxygen comes in, and comes to the chlorophyll, and the chlorophyll takes the hydrogen and oxygen and separates them and sends the hydrogen on...and for every hydrogen we got, we could add another charge to the APP...and then we sent it on to the Calvin cycle and back at the chlorophyll they took the oxygen and gave it to the place that transports it out of the leaf to put it back in the air...
2	What the plant eats and needs to survive	What the plant needs to sustain life. It is a sugar...It comes from getting water and sunlight and bringing those all together to create the sugars.
3	Things that the plant gets energy from such as sun, water, and minerals	What the plant makes and can use to get energy...from the whole process, the photosynthesis of getting energy from the sun and then doing everything it does.
4	Water, nutrients, vitamins, minerals, and fertilizer	Anything the plant needs to grow; that can be water, sunlight, or sugars -CO ₂ comes from the humans, and sunlight comes from the sun, water...from rain, the water cycle, and the sugars are formed through the process of photosynthesis.
5	Minerals, mineral sugar in water	C ₆ H ₁₂ O ₆ or variations of that. And it is created in each plant cell in the leaves. It is used to grow itself...I think of that drama, so we can start with bringing in the water and then the chlorophyll ripping it apart and using that energy and giving it to the cell wall and the cell wall giving the energy to...Kelvin and the Kelvin ripping things apart and putting things together to create pieces of C ₆ H ₁₂ O ₆ and then the phloem bringing water out and then, yeah.

Table 4.7 Continued.

6	Water, sugar, and minerals	What plants use and produce to make energy through the process of photosynthesis –through the roots come water that the plant needs and it goes through the whole process of photosynthesis in the chloroplasts...it takes the water and breaks it apart and sends it to the t-membranes and those t-membranes use it and charge an APP to make it an ATP...and sends it to Calvin which then they use it to make a sugar, but have to do it so many times to get a C ₆ H ₁₂ O ₆ so once they do that they have made the whole process of their food.
7	Energy	The plant's energy...it takes in sunlight and it changes it to the food, which gives it the energy it needs to live and to grow.

Note: For anonymity, the order of students is not the same as in Table 4.6 which provides demographic information.

Students' improved understanding of plate tectonics was also clearly shown through the interviews. During the initial interview, students used phrases like, "no recollection of ever learning about plate tectonics" and "not much" to explain their background in plate tectonics. Plate tectonics was not mentioned or taught during the time interval between the first and second interviews, so it was not asked about in the second interview. In the final interview, students were asked, "What is a tectonic plate?" and "What does it help explain?" The initial and final responses are included in Table 4.8. With the possible exception of student two, each final response was more detailed than the initial responses; a difference I believe is not an artifact of the different data collection methods (note-taking vs. audio-taping and transcription) in the two rounds. Notice that all final responses (Table 4.8) included connections to events like earthquakes and volcanoes. Only minor misconceptions were expressed during the final interview such as: the plates were under the earth (student 1) instead of the surface, and that plates

were a part of the earth's crust (students 6 and 7) instead of "the crust is broken into plates". It should be noted that the final interview was conducted just days after completing the final lesson on plate tectonics.

Table 4.8. Comparison of Initial and Final Student Interview Responses for Defining Plate Tectonics.

Student	Initial interview. What do you know about plate tectonics?	Final interview. What is a tectonic plate? – What does it help explain?
1	No recollection of ever learning about plate tectonics ...involved in the movement of the earth	A plate that's under the Earth that moves creating different effects. Convergent plates come together and they can either form mountains or they can form trenches... the divergent plates come apart and that's like the Mid-Atlantic ridge where new rock comes up. They've explained earthquakes, why in the middle of the ocean, it is higher than the other parts of the ocean...and why mountains have formed.
2	All the continents were connected into one piece of land called Pangaea. Plate tectonics cause earthquakes which happen at fault lines where plate tectonics hit each other, eventually causing the continents to split.	A piece of the Earth that's moving and it can cause earthquakes or volcanoes. The way the continents seem to be moving apart...there's fossils that are similar, different traits in the countries across the ocean like Africa and South America.
3	Not much.	The crust is broken into different plates and then it explains how they have moved and how they are moving so that explains things like earthquakes and volcanoes.
4	It involves moving parts of the earth. Connected to the Grand Canyon, mountains, and earthquakes... relate to splitting continents.	The Earth's crust and part of the mantle are made up of plates that kind of float around and that explains... volcanoes and mountains and faults and...the movement of them and Pangaea.

Table 4.8 Continued.

5	Has to do with plates shifting – plates collide to form mountains.	Made of the crust and part of the mantle of the Earth and there are several plates. They come together at convergent, transform or divergent boundaries. They help explain how the continental drift happened, why earthquakes happen, how volcanoes occur, why the Himalayas keep growing.
6	Transfer of energy-similar to something heating up in a pan. Energy and earth make-up are two ways plate tectonics can explain our earth.	Part of the Earth's crust but it moves on top of the asthenosphere. All these different plates on the earth and they're not all connected cause they're floating on this gas. Explains the theory that all the continents were close together and that over time the plates have moved. Helps explain why we have earthquakes or tsunamis because of plates that are either convergent or divergent and are either spreading apart or coming together and creating earthquakes.
7	Don't know, has to do with the structure of the Earth and how it's put together.	Part of the Earth's crust that is split into different plates and it moves from the liquidy mantle below it. Helps explain where earthquakes happen, where mountains are formed, all different trenches and different features on earth. It helps determine where most of the earthquakes will happen.

Understanding Formative Assessment

The first research question also explored the extent to which students' understanding of formative assessment improved through the course. To establish baseline data, students were asked to define formative assessment in their science notebooks before the intervention began. Also, the initial student interviews included questions about formative assessment. Using this prior knowledge as a benchmark, final understanding was demonstrated through post-interviews and the final exam. In addition,

the final exams demonstrated that students developed an appreciation for formative assessment as explained in the sub-heading below.

Students had been exposed to formative assessment before the intervention and were familiar with the term. Although our program does not include a specific class on assessment, each of the methods courses includes some coursework on assessment. Earlier in this course, students had designed and turned in three lesson plans in which they were expected to explain how formative or summative assessment would take place. Through class discussions, readings, and as students explored assessment tools, some students had already developed a working knowledge of formative assessment. When asked to define formative assessment in their notebooks, student responses included a variety of brief definitions (Table 4.9). Ten of the 24 students expressed a basic understanding of formative assessment (two or more components from the table); however, none of them mentioned using formative assessment to help students self-assess their own understanding or the value of teacher feedback to improve student understanding. Initial student definitions seemed to be recalling parts of a memorized definition that included phrases like “used to measure progress” or “assessment for learning” or “ongoing assessment” or “assessment through observation” or “checking what they learned that day”.

Table 4.9. Student Pre-study Definitions of Formative Assessment in their Science Notebooks

Key components of formative assessment	Student definitions that included this component	Sample of formative assessment definition taken from student notebook
To measure student understanding	9	...“is informational and gives you an understanding on how well students understand something.” “shows what students have learned”
To help teachers improve their teaching	7	“...see what they [students] have learned and change/alter lessons according to that.”
To help students improve their learning	0	[no samples]
During the instructional process, ongoing	14	“...tests, quizzes, used during the learning process.” “...preplanned, used throughout learning process.”

Note: This assignment was given before the intervention was conducted. The same student could be counted for more than one component. $N=24$

The seven students interviewed at the beginning of the study provided a slightly more detailed picture of students' initial understanding of formative assessment. Of the seven students interviewed, four demonstrated a basic understanding. For instance, one student mentioned formative assessment's value for teachers, “a good way to measure students' progress”, value for students, “as a student, it helps to measure own progress”, and the variety of tools, “using tests, rubrics, and anecdotal records”. Unlike the definitions in the notebooks, three of the students did mention the connection to help students improve their own learning with comments like “to help the student know what

they don't know", "to understand their own learning" and "helps both students and teachers". One student provided a strong definition, but claimed she "does not know how to incorporate it into teaching".

Although many students seemed to have a basic understanding of formative assessment before the study, the depth of their understanding improved through the intervention. One of the final essay questions on the end-of-semester exam asked, "What is formative assessment? What have you learned about formative assessment this semester in this class? Examples?" Each student provided multiple descriptions of what formative assessment is designed to do. Most of those descriptions (92%) included the importance of learning what students know and using that information to guide instruction. It was interesting to see the increase (from 0% to 63%) in responses mentioning how formative assessment helped students develop their own learning. Most students (88%) connected their explanation to their own learning experience in the course (Table 4.10). The quotes in Table 4.10 show that students noticed the importance of the formative assessment process for identifying where they needed help, the value of learning together with peers, the value of student notebooks and ungraded assignments, appreciation for individualized instruction, and providing students with evidence of their own learning.

Table 4.10 Student Understanding of Formative Assessment through Connections to their own Learning Experience.

Quotes from student essays

1. It helped reassure me that other people are going through the same struggles as me.
 2. I found that by doing formative assessments in class, such as the probes, as a student I was better able to figure out what I knew and where I needed more help.
 3. I thought that I understood everything there was to understand about plate tectonics. After Professor Brower answered questions that other students had, I ended up learning a lot more about that topic.
 4. ...the science notebook; it was a great way to have students write what they were thinking without the fear of being wrong.
 5. Un-graded worksheet...got us thinking critically about the topic before we even began to really learn it, and peaked [*sic*] our interest in the subject, making us want to learn more about it.
 6. I felt like learning was a bit more individualized, and I really like that...
 7. With a group...we were able to verify what we knew, answer each other's questions, and realize some questions we still had. It was so helpful to see what I had learned.
-

Appreciating Formative Assessment Beyond learning about formative

assessment, students also developed an appreciation for using it in the classroom. As students shared their reasons for accepting formative assessment, I was curious about what brought about the change. Searching through their final essays, I looked for evidence of a “conversion experience” in which students identified a change in their acceptance of formative assessment. Listed below are a few of these “conversions” in students’ own words:

This has changed my thinking of formative assessment, because I used to think that it was only quizzes. I have learned that there are so many other ways in which you can collect artifacts from your students to see how they are learning, and that has been very beneficial (Student 1).

The first time that we had to create a concept map I wasn't entirely thrilled because the topic was photosynthesis and I had no idea what I was doing. I appreciate them so much more now! By the time we got to the topic of plate tectonics and had the option of either creating a concept map or writing in our journal, I wanted to create a concept map (Student 2).

What helped me really understand formative assessment is when I took a quiz and explained what I didn't know and then saw how the next class was modified to help us. Because I saw how this was helpful, I think that I would definitely use this in my own teaching someday (Student 3).

I want to make my class a safe place where questions can be asked. I also want to use that information to teach to the students' needs. I might use a combination of entrance and exit slips to decide how well my students are catching on to what I am teaching them. That is one way they can ask questions and I can use those questions to inform my teaching for the next lesson. This has definitely changed as a result of this class, because I did not fully understand formative assessment before. Now I know what it is and I'm really excited to use it! (Student 4)

In the first quote, experiencing a variety of assessment tools freed up this preservice teacher to make assessment happen beyond quizzes. I think she already recognized the value of formative assessment, but was encouraged to find other tools to use with her future students. The second student shared her unexpected appreciation for concept maps. During the intervention, I had a similar experience myself. I never liked the ambiguity of concept maps, but learned that they can provide a useful method for helping students uncover what they did not understand. The third student recounts how she saw her specific questions guiding instruction. When she saw how the instruction adjusted to meet her learning needs, she was convinced that she wanted her own students to experience a similar connection someday. The fourth student took ownership of formative assessment. Although I never used entrance or exit slips in my class, this student appreciated my efforts to elicit students' written questions. She was able to recognize the importance of using students' questions to guide instruction and has

determined her own methods of implementation. Each student shares a different aspect of their own learning experience that made formative assessment valuable for their own teaching.

Learning from Formative Assessment

The second research question asked, How can formative assessments be designed and used to gauge student understanding of both science understanding and formative assessment in a science methods classroom? The earlier description of the intervention shows how the course design allowed for the integration of learning about formative assessment while using formative assessment to learn science content. This section considers what was learned from the formative assessment. Student prior knowledge in science can be divided into three categories; missing, incomplete, or strongly held misconceptions (Chi, 2008). Research questions 2a and 2b consider how formative assessment could be used to identify these categories in the areas of science content and understanding formative assessment respectively.

Formative Assessment: Misconceptions and Incomplete Science Content Knowledge

Research Question 2a reads, How can formative assessment be used to explore what preservice elementary teachers already know and differentiate between incomplete knowledge and strongly held science misconceptions? Different types of formative assessment provide different insights into student learning (Naylor, Keogh, & Goldsworthy, 2007; Osborne & Freyberg, 1985; Stiggins, Arter, Chappuis, & Chappuis, 2006; White & Gunstone, 1992). Some tools were designed specifically to identify

student prior knowledge, like the diagnostic test and the pretest. Other tools were used to identify students' incomplete knowledge, including the group concept maps and the non-graded quiz. Students' deeply held misconceptions needed to be identified by looking at student performance over time to show that they resisted instructional efforts.

Exploring Prior Knowledge The AAAS diagnostic tool (American Association for the Advancement of Science, 2011) was designed to identify student misconceptions. The results in Table 4.2 identified two areas in which my students held significant misconceptions; plant food/energy and plate tectonics. However, the diagnostic tool did not provide any differentiation between a student with a deeply held science misconception and missing or incomplete knowledge.

During the first week of the intervention, each student was asked to draw a diagram depicting photosynthesis in their science notebooks. The goal of these diagrams was to determine students' prior knowledge about photosynthesis. Many diagrams were so basic (see Table 4.11 for descriptions of student diagrams assigned to Group 3) that they revealed little about students' prior knowledge except that most of the knowledge was missing. However, the diagrams did show some misconceptions like food going into the plant or using heat (instead of light) from the sun to perform photosynthesis.

Each of the three groupings of student drawings/diagrams of photosynthesis in Table 4.11 consisted of roughly a third of the students in the class. Drawings included in the first grouping showed correct prior knowledge and provided the most detailed drawings. The second grouping of student drawings included some detail, but each drawing displayed either student confusion or student misconceptions. The third

grouping consisted of simple drawings that provided little useful data. The student diagrams demonstrated a range of student prior knowledge. Some students were prepared with a basic understanding of photosynthesis including reactants, products, and direction of the processes (the first group of student drawings). Other students had learned some of the reactants or products for photosynthesis, but their drawings showed mistakes in their understanding (drawings included in group 2). The last group of drawings depicted no more than a plant in the sun which demonstrated a very incomplete knowledge about photosynthesis.

Table 4.11. Using Student Diagrams to Show Misconceptions and Incomplete Knowledge

	Diagram shows picture of plant and Sun	Arrows show correct motion of particles	Carbon dioxide and/or oxygen included	Food or sugar included as a product	Diagram shows water going in the plant	Obvious misconception shown
Group 1	6	6	5	4	3	1*
Group 2	6	1	5	3	1	2*,1**,1***
Group 3	7	1	0	0	0	1*

Note: Numbers indicate number of students. Specific misconceptions were: *food, sugar or nutrients going into the plant, **plant uses heat from the sun, and ***flower petals do photosynthesis, ($N=19$).

On the Monday of week four, I collected data to reveal students' prior knowledge on this topic as well. Before studying plate tectonics, students were given a pretest with 21 questions about plate tectonics. Most students (88%) provided less than three correct answers on the pretest. The highest score was seven correct answers. When given the pretest, students were told to answer the questions they thought they knew the answers to, and to leave unknown questions blank. Only two of the 24 students attempted to answer

more than half of the questions. The quiz responses were mostly blanks or “I don’t know”. Assuming that students were making an honest attempt to show their knowledge, the pretest indicated very little prior knowledge of plate tectonics.

Incomplete Knowledge Students were given formative assessment probes during the first two weeks of the intervention. With each formative assessment probe, some students displayed misunderstanding, but it was impossible to differentiate between science misconceptions and incomplete knowledge. As an instructor, it was difficult to know how to use this information to guide instruction. Guided by the conceptual change model, I could confront student misconceptions and provide evidence for scientific explanations. Guided by a concept accumulation model, I could identify and address areas of students’ incomplete knowledge. Considering the method that my preservice elementary teachers could implement as a first step towards reducing science misconceptions, I chose to identify and address missing science knowledge instead of confronting misconceptions. A second reason for the choice is that I believe teachers can learn with students through concept accumulation, whereas I believe it requires significant content understanding to successfully confront student misconceptions. Therefore, subsequent formative assessment tools (concept maps, non-graded quiz, and the pretest) were used to identify gaps in students’ knowledge which then guided the topics included in subsequent lessons.

During the second week, students were asked to draw a concept map in their science notebook to demonstrate their understanding of plant food. The initial concept maps that they drew could be categorized into three groups: (1) student draws a concept

map that is clear without misconceptions (38%), (2) student shows most of the information, but diagram is confusing (21%), (3) student shows obvious misconceptions in their understanding of plant food (42%). A typical sample from group one and two is shown in Figure 4.10 (a group three concept map is shown in Figure 4.2). It became obvious that students needed some instruction on drawing concept maps. My instructional response is described in my description of the intervention.

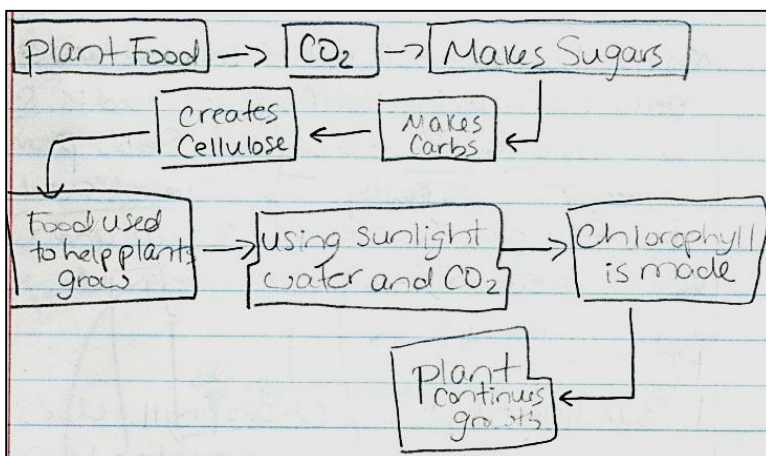
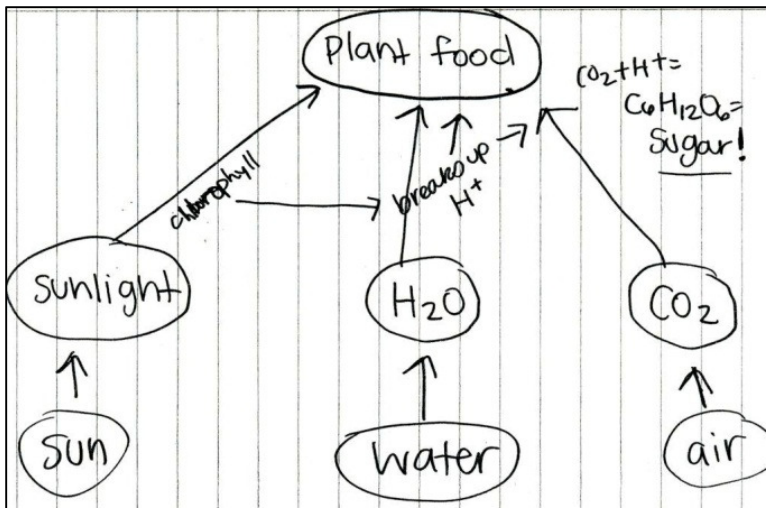


Figure 4.10. Student concept maps. The first student demonstrates basic understanding. The second student shows correct information, but in a confusing linear sequence.

Realizing the challenge of individual concept maps, I decided group concept maps could be used by students to facilitate learning from each other. One of my research advisors suggested that each group could generate a set of questions as they constructed the map. Using the concept mapping activity to generate student questions placed students in the position of analyzing their own understanding and provided focused guidance for classroom instruction. Priority for instruction could be determined by repetition of information included or omitted in responses. Connecting back to the research question, student generated questions provided useful formative data that revealed self-identified gaps in student knowledge.

Science Misconceptions Continue Student's incorrect understanding is not always resolved by identifying and addressing incomplete knowledge. One probe asked students about a scientific definition of food. The results (Table 4.3) showed that most students struggled with a scientific understanding of food as a source of energy. This non-scientific understanding of food carried over to plant food as well. Students wanted to define food as the material that plants take in instead of the sugar they produce through photosynthesis.

The results of the final quiz on plant food and photosynthesis indicated that while students may have increased knowledge in the subject, some of them still held onto misconceptions. Although most of the students provided a correct scientific explanation of plant food as the product of photosynthesis called glucose or sugar (58%), a number of students (21%) combined the scientific explanation with other examples such as water, sunlight, CO₂, or intermediate molecules like ATP. The last group of students (21%)

unswervingly held the misconception that plant food is the water, sunlight, and/or nutrients taken into the plant instead of the sugars produced by the plants.

After identifying those students with persistent misconceptions concerning plant food, I looked back on the data to explore early indications or characteristics of the group. One early indication of their misconceptions was that most of them were also in the group with minimal plant food concept maps that also showed apparent misconceptions. However, it should be noted that other students with minimal plant food concept maps did not show misconceptions in the final quiz. A second, stronger indication was that many of these same students demonstrated misconceptions on the apple tree probe (Table 4.5). However, other students who did poorly on the apple tree probe resolved their misunderstandings. In hindsight, I should have followed up with the small group of students who showed apparent misconceptions on the apple tree probe. I could have listened to their thinking, asked them to write a follow-up explanation, or I could have paired them up with other students to talk through their understandings. One final characteristic of this group (persistent plant food misconceptions) is that most of the students intend to teach early childhood or early elementary which may have influenced their motivation to learn this challenging content material.

Summary: Using Formative

Assessment with science Content Knowledge Throughout the intervention,

formative assessment was used to help the teacher (and the students) identify some of the prior knowledge held by students. When an apparent misconception was identified, I realized that it takes time to determine if it is deeply held. In the meantime, formative assessment was used to identify students' incomplete science content knowledge. In this

study, it was helpful to use a tool like a group concept map or a non-graded quiz to help students generate questions. These student questions provided useful insights into students' self-identified incomplete knowledge, which was then used to guide instruction. Identifying a deeply held misconception may take time to see if the misconception persists after instruction. In this study, the final quiz on plant food revealed that a number of students still held misconceptions concerning plant food.

The results also indicate that students appeared to prefer learning about plate tectonics over plant energy/photosynthesis. Student essays and interviews that mentioned plate tectonics did so in a favorable light. Reflections that mention plant energy or photosynthesis used words like “confusing” and phrases like “difficult to understand”. These student attitudes may be directed towards the content itself, or the students may prefer learning new material over correcting incorrect knowledge.

Formative Assessment:
Misconceptions or Incomplete Knowledge

Research question 2b reads, How can formative assessment be used to explore what preservice elementary teachers already know and differentiate between incomplete knowledge and misconceptions about formative assessment? This section will begin by looking at students' prior knowledge from initial interviews and notebook entries. Recognizing what students have learned can provide insights into previously incomplete knowledge. The few misconceptions mentioned in this section are my interpretations based upon student comments. Without repeated assessments over time, it is difficult to identify any deeply held misconceptions.

Prior Knowledge about Formative Assessment The tool used to identify what students already knew about formative assessment was an early entry in their science notebooks. In this entry, students were asked to write a personal definition of formative assessment. The data shown in Table 4.9 revealed how students' understanding of formative assessment varied at the beginning of the study. Although some students were incorrect in their definition of formative assessment, most students provided correct, yet incomplete, short definitions.

Initial Misconceptions about Formative Assessment Just as incomplete definitions give indication of incomplete knowledge, incorrect definitions can help identify apparent misconceptions. Table 4.12 shows some of the inaccuracies in student definitions along with possible student misconceptions about formative assessment. The definitions are quoted from student notebooks. The misconceptions are my interpretations, recognizing that part of the incorrectness might be due to the brevity of student entries. The first misconception was that formative assessment is informal rather than a "planned process..." (Popham, 2008, p. 6). Teachers need to know that formative assessment involves much more than looking around a classroom to observe student understanding. The second misconception involved some students' belief that formative assessment must always be a graded assignment or others' belief that it must always be a non-graded assignment. The identification of formative assessment lies not in grading, but in how the results are used. The third misconception, or possibly an omission, is simply that none of the initial entries in student science notebooks mentioned that

formative assessment can help students see what they need to do to improve their own learning tactics.

Table 4.12. Incomplete or Incorrect Student Definitions of Formative Assessment before the Study

Incomplete or incorrect definition of formative assessment:	Misconceptions which might result in such definitions
“Part of everyday learning. Seeing each day where children are at” “Continuous assessment (usually observation type assessments)”	FA is informal, even spontaneous, rather than a formal, prepared assessment.
“type of assessment that is like formal, but it’s a letter grade instead” “finding out information-doesn’t count for points-ongoing-subjective”	FA is defined by being graded or not graded.
No mention of students learning from FA	FA is only for teachers.

Note: Student definitions were written before the intervention. Misconceptions were inferred from the student definitions.

Incomplete Knowledge of Formative Assessment The development of student understanding of formative assessment can be portrayed by using multiple sources of data. Using students’ own words, I will include the learning sequence of three students to show how their incomplete understanding became more complete as the course progressed. The first data source is the initial entry in their science notebook. The second data source is from the mid-study interviews, where the student was asked “How has your understanding of formative assessment changed through this learning experience?” At the end of the study, students wrote a final essay in which they were asked to define formative assessment and explain what they have learned about formative assessment.

These three students provide a sequence from incomplete to deeper understanding of formative assessment.

Student 1:

FA: type of assessment that is used to guide instruction. used to measure progress. Could be given during a unit. Could be formal or informal. (Student notebook)

I: How has your understanding of formative assessment changed through this learning experience?

S: I guess I wouldn't have thought of using things like these.

I: the probes?

S: yeah, I was just thinking of formative assessment as more narrow, of just checking in on students understanding to guide your instruction...or it could even be at the beginning where you are just trying to figure out what they already know...like having students ask questions...like that we wrote down (Student interview)

Formative assessment is assessment that is completed during learning in order for students and teachers to gain information which is then used to guide future instruction. Formative assessment is done in order for teachers to assess student progress in understanding content or meeting learning objectives. It is used to help teachers know what students are or are not understanding so they know whether they need to spend more time teaching a particular concept or skill or if students are ready to move on. Formative assessment is not only helpful to the teacher, it is also helpful for the student because it shows them what they know so that they know how to improve. Giving students the opportunity to show their knowledge during learning rather than just at the end of learning is beneficial to them because they are forced to think through what they know which improves their learning and gives them specific feedback on what concepts or skills they need to spend more time learning or practicing (Final essay).

Student one begins with an acceptable definition of formative assessment as it is used to guide instruction. However, the interview response shows that her definition has expanded to include other methods like the probes used in class and students writing down questions for the teacher to use. She also adds the value of determining student initial understanding. In the final essay, this student demonstrates even broader understanding of formative assessment as she includes both students and teachers as

recipients of the data. As a new addition, she describes how formative assessment can force students to think through their understanding and the helpfulness of specific feedback. The final explanation shows how six weeks of instruction has added to her understanding of formative assessment.

Student 2:

FA: assess the progress made from the last assessment (Student notebook)

I: How would you say that your understanding of formative assessment changed as we used these different tools?

S: I don't know. I'm probably am not so negative against it now...and it's something that you can use any old day...but I still do like the informal assessment like...draw a concept map of what you understand and write down on your answers on this ungraded quiz...I still like the looseness of that

I: So the fact that it was ungraded was important to you?

S: Maybe not so much that it's ungraded, but that I could just feel free to write whatever rather than thinking that I had to write what I know to get a grade in it? I was thinking I have to write what I know to show that I know it (Student interview).

Formative assessment is a tool that is helpful for both the student and the teacher. It can be in virtually any form; probes, non-graded quizzes, interviews, journal entries, etc. By administering these assessments, teachers can use the information to see what the students know and don't know. Then they can adapt their lessons accordingly. Formative assessment can also show a teacher how he/she could better teach students (Final essay).

Student two begins with a narrow definition of formative assessment as a tool to mark progress through a unit. In her interview, she begins with her change in attitude that she's not so negative against it now, that she appreciates the "looseness" of it. This suggests that she dislikes evaluation and has learned that formative assessment might be helpful to her learning. Even the grading comment seems to confirm her appreciation of assessment used for learning instead of evaluative purposes. In the final essay, she recognizes the usefulness for students and provides examples of a variety of tools. Most

importantly, she confirms its usefulness towards becoming a better teacher. This sequence also shows added understanding of formative assessment over the course of the study.

Student 3:

FA: see what they have learned and change/alter lessons according to that (Student notebook)

I: How has your understanding of formative assessment changed through this experience or has it changed?

S: Formative assessment wasn't something I was really familiar with before this class, and I have realized that it is really helpful in any classroom setting to know where your students are and what they need to learn. Most of the classes I was in before, they just taught you what they thought they needed to teach you and that was it. And you were tested on it and if you didn't know it, then it was too bad.

B: So this experience, you felt like the formative assessment was useful for your understanding?

S: Yup.

B: And for yourself?

S: Yeah. Like that you were making sure that we all understood what you wanted us to know and not just, I don't know, not just testing us and giving us a grade (Student interview).

Formative assessment is checking what your students know, what your students are struggling with, and what you, as a professor, need to review or re-teach periodically throughout a lesson. Instead of waiting until the end of the unit to see what your students did and didn't learn, the teacher makes it his/her own personal job to make sure that each and every student understands and succeeds by the end of the unit (Final essay).

The third student begins the study with a correct, but basic definition of formative assessment. In her interview, she suggests that formative assessment provided a different relationship between teacher and student. I think she has appreciated the increased communication that formative assessment provided for her learning and recognizes that this makes for an improved learning environment. In the final essay, she builds on this

ownership of student learning, suggesting that teachers take more ownership of the success of their students.

These three students provide a glimpse into the learning process of students in the course. Each connects to different aspects of formative assessment. However, each student demonstrates how her understanding has become more complete. Recognizing that each learner comes to a topic like formative assessment with prior understandings and misunderstandings, these examples show how these learners constructed increased understanding as the study progressed.

Student Reflections on Learning about Formative Assessment. The final essays provided a wealth of insights into students' experience with learning about formative assessment in this course. Students were asked to identify specific aspects of formative assessment that they learned in this class. Most of their responses related to one of the following four categories. First, they learned that formative assessment can be done in a variety of ways, using a variety of tools. Second, they learned that formative assessment helped teachers to show an interest in student learning. Third, they learned that formative assessment helps students better recognize what they need to learn. Fourth, they learned that formative assessment helps teachers make more effective use of instructional time. These categories are elaborated in the following paragraphs.

The variety of tools available for formative assessment provides a freedom that allows teachers to tailor assessment for different tasks and different students. Many students included specific examples of the variety of tools now available to use in their teaching. The concept of formative assessment can be attractive, but without clear

examples of how it can be done, teachers may never get started in earnest. Here are some of their own accounts

I've learned that formative assessment is very important, especially looking back at our class. If you hadn't assessed us with pretests, quizzes, reflections, etc., you wouldn't have known if we entirely understood what you were teaching us. Because you assessed us through various ways you were able to find that we did not comprehend details to certain concepts. (Student essay)

I have learned that there isn't just one type of formative assessment to use. There are so many kinds that we discussed in class that we did and gave back to the teacher. We used ideas like a group concept map, drums [?], non-graded quizzes, probes, SMART board pictures, website search, and leaf writing. This was great for me to know what I know, and what I don't know. (Student essay)

In this class it has become more clear to me what formative assessment is as well as what it looks like in the classroom and how it can be used to inform instruction. We participated in many examples of formative assessment that gave me an idea of how it can be used in the classroom including non-graded quizzes, probes, concept maps, and our science notebooks. (Student essay)

In the second category, students recognized that formative assessment changed their view of the teacher. By eliciting student understanding, and using it to guide instruction, students recognized that I was interested in their learning. Although I may be very interested in my students' learning, it does little for them unless they recognize this.

The excerpts below demonstrate the importance of learning what students know:

I have really gotten to see how formative assessment works this semester. I never really understood what it was until I had it demonstrated for me. I have learned that formative assessment really wants to know how well the students are learning. (Student essay)

I have learned that formative assessment involves students much more than summative assessment. Based on my experience, formative assessment makes me feel more cared about and valued as a learner. It makes me feel as though the teacher is genuinely interested in what I am learning and the progress I am making. (Student essay)

Over the period of this semester and after taking this class, I have realized how important it is to use formative assessment because I think that sometimes teachers get caught up in getting all the material taught that they forget to stop and observe to see what the students know or don't know without being concerned about awarding points for it. (Student essay)

The third category relates how formative assessment helps students with their own learning. Students often feel alone with the challenge of learning and wonder if they understand something. Without feedback or updates along the way, students can be mystified about their current understanding or lack of understanding. According to these students, formative assessment helps students in the learning process. Each student recalls a different aspect of formative assessment used in the class and connects it to their own learning:

Using formative assessment this semester helped me to understand the teacher's goals for our class and to know whether or not I am on track with those goals. It was helpful to me because I did not feel the pressure of getting a grade. Rather, I felt as though I was intrinsically motivated to understand the topic and this also sparked interest in the topic at hand. (Student essay)

However, I found that by doing formative assessments in class, such as the probes, as a student I was better able to figure out what I knew and where I needed more help so that I could better understand a concept. It was not just the teacher who was learning about my understanding of a subject but I was contributing as well. (Student essay)

I have also learned that by finding out specific questions that the whole class might have, and reviewing those things, there are other students in your class that will learn new things that they may have thought that they understood and didn't think that they had questions about. For example, I thought that I understood everything there was to understand about plate tectonics. After Professor Brower answered questions that other student's had, I ended up learning a lot more about that topic. (Student essay)

The fourth category is concerned about using instructional time effectively. By the time college students are juniors and seniors in the education program, they have experienced all kinds of classroom experiences. Coupled with hours of classroom observations, they recognize that some instruction is unnecessarily repetitive and many students become bored learning the same material again and again. This lack of efficiency can develop lazy learners who know that if they miss something, it will certainly come around again. Using formative assessment data can increase the efficiency of classroom instruction:

For me I felt like learning was a bit more individualized, and I really like that, I feel like at many times our educational system teaches students something they may or may not need to re-learn or learn something again. If a student already knows a lot about something or a specific aspect of a topic being taught is it worth our time to reteach it or is it better to try to teach them something new or expand on what they are being taught. (Student essay)

I have learned that formative assessment does not mean informal assessment and is not another way to test students, but rather a way to gather information on what students know to guide teaching. I really like this idea because I have sat in some classes where I already knew the information they were teaching, and as a student, you get bored, so I really like the idea of finding out what students already know and do not know and teaching them accordingly. (Student essay)

One thing that I have learned about formative assessment from this class is that it can be a useful tool to use in our classrooms. Before we began studying photosynthesis and plate tectonics, we would be given a quiz that was not graded to see what we knew about photosynthesis and plate tectonics. Based on that information from the quiz you could focus your teaching on the topics within photosynthesis and plate tectonics that are not clear to the students. This would be a good way to see what our students know about topics before studying them. That way the teacher does not have to focus on a topic that every student knows and can focus on the ones that are unclear to students. (Student essay)

As students identified what they had learned about formative assessment, most comments related to the four categories above. Some students identified their own incorrect thinking such as: “Prior to this class I had only seen it as an observation tool” or “the only form I knew about was quizzes” or “I have learned that formative assessment does not mean informal assessment”. As the instructor and researcher, I found it difficult to identify student misconceptions about formative assessment, but found it helpful when students recognized their own incorrect knowledge. This knowledge will guide my future instruction in formative assessment.

Summary: Learning about Formative Assessment Research question 2b focused on how formative assessment can be used to explore prior knowledge and to differentiate between incomplete knowledge and misconceptions about formative assessment. Science notebook entries and initial student interviews gave insights into student prior knowledge on formative assessment. The initial data showed that students demonstrated incomplete knowledge and some had apparent misconceptions about formative assessment. When students have a basic, but incomplete definition, it could be interpreted as incomplete knowledge, especially if further instruction improves the definition. If an incorrect definition persists after instruction, it may be considered a deeply held misconception. Without research to identify misconceptions of formative assessment, my attempts to identify student misconceptions are simply personal interpretations. Looking at student work at the end of the study, students’ understanding about formative assessment became broader and more complete. Recognizing that formative assessment is not universally defined and has various interpretations, it is difficult to compare student final definitions

to an accepted standard which also makes it difficult to identify student misconceptions. This ambiguity made it difficult to answer this research question with confidence.

In spite of the difficulty in identifying misconceptions, the students and I did develop an appreciation for formative assessment. As I incorporated strategies into the course, I realized they provide me with helpful insights into student learning. Reading through students' final essays, it appears that they learned to value it as well. For me, the first step was to appreciate the process and now I am learning how to improve my use of formative assessment. I hope that many of these students may have a similar experience in their own elementary classrooms.

Student Efficacy and Attitudes towards Teaching Science

The third research question reads, Recognizing that many elementary preservice teachers may have low science teaching efficacy, is there a relationship between increased familiarity with formative assessment in science and future teachers' science teaching efficacy? Teachers with higher science teaching efficacy are more likely to use student centered teaching methods as opposed to primarily lecture and textbooks (Czerniak & Haney, 1998). If formative assessment is a useful tool in promoting more student directed learning, it becomes worthwhile to explore preservice teachers' science teaching efficacy and attitudes after they participate in the formative learning process. The following sections look at pre and post scores of the STEBI-B survey, comments from notebooks/interviews, and student responses from the final exam essays.

STEBI-B Survey

The STEBI-B was designed by Enoch and Riggs (1990) to measure science teaching efficacy amongst preservice elementary teachers. The results are divided into two scores, the Personal Science Teaching Efficacy (PSTE) score and the Science Teaching Outcome Expect (STOE) score. The PSTE score measures preservice teachers' confidence in their own science teaching abilities or how well they believe the claim "I can effectively teach science" (Ramey-Gassert, Shroyer, & Staver, 1996, p. 308). The STOE score measures how much a teacher believes student learning can be influenced by effective science teaching (Enochs & Riggs, 1990). As students learn more effective science teaching methods, these scores are expected to increase. Increased scores may or may not be the result of students' growing familiarity with formative assessment during this study, but they provide one tool to measure changes in these students' beliefs.

Table 4.13. Results of the STEBI-B survey

STEBI-B Test	Pretest	Pretest <i>SD</i>	Posttest	Posttest <i>SD</i>	Change	Effect Size
PSTE*	41.54	6.96	49.21	4.96	7.67	1.16
STOE**	34.17	3.80	36.79	4.29	2.62	0.85

Note: * $t=4.39, p<.001$. ** $t=2.24, p=0.030$. $N=24$.

The STEBI-B results (Table 4.13) show considerable change in students' confidence in teaching science (PSTE) and expectations for student learning (STOE). Both effect sizes are greater than 0.8 which indicates a large effect. Compared to other studies using the STEBI-B (Christol & Adams, 2006; Finson, 2001; Watters, Ginns, Neumann, & Schweitzer, 1994; Yilmaz & Cavas, 2008), the students in this study

showed greater efficacy gains in both science teaching and expected student learning than those recorded in other studies of preservice elementary teachers (Table 4.14).

Table 4.14. Comparing STEBI-B Scores

Name of author(s)	Brower (2012)	Yilmaz & Cavas (2008)	Christol & Adams (2006)	Finson (2001)	Watters et al. (1994)
PSTE gain	7.67	0.15	3.16	6.93	0.96
STOE gain	2.62	-0.42	0.87	2.59	-0.83

Note: Studies selected for comparison recorded pretest and posttest mean scores for both the PSTE & STOE.

Initial Attitudes toward Teaching Science

While science teaching efficacy is defined by a teacher's belief in his or her ability to teach science, preservice teachers can be influenced by other attitudes towards science and teaching science. In the first entry in each science notebook, students were asked the question "How do you feel about teaching science?" Of the 24 entries, three were primarily positive and included words like excited, fun, and comfortable. The reasons given for these attitudes were that students enjoyed science and/or want to teach science in fun, exciting, and/or hands-on ways. An example is

I am so excited to teach science, it is one of my favorite subjects, however it is the subject I have had the least "in class" experience with. I just love how interactive/hands on this subject is, as well as how excited kids are to learn about these things.

Eleven of the 24 entries were primarily negative and included words like nervous, lack of confidence, unsure, uncomfortable, inadequate, not excited, scary, or frightening. These students were concerned with their lack of science knowledge, lack of science teaching skills, and/or disinterest in the subject. Two examples are

Science is an area that I really don't have much attraction to. Science is something that can be confusing to me to which I don't understand it. I feel like it would be a struggle to teach science because I'm not confident enough in myself to understand it. I would have to do a lot of researching and learning.

I am nervous to teach science because I was never interested in science growing up and I feel that I would be underprepared. The way it was always presented to me was long, boring, and un-engaging and that's what I associate science with. It almost stresses me out thinking that I will have to teach something that I feel I don't know anything about. I want to be engaging and for the students to enjoy the class.

Ten of the 24 students had nearly equal positive and negative comments and shared combinations of the comments from both groups. Examples include

I believe teaching science will be both challenging and fun. I think it will be challenging because my science skills as well as math skills used in data are not very strong. I think teaching science will be fun, though, because it will be engaging for students and hands on.

I'm excited to teach science because I think that there are a lot of engaging activities you can do with science. I'm also nervous & scared to teach science because I feel that science is not my strong area. I feel like I don't know as much about science as I do in other subjects like math, so I'm nervous about that.

I feel nervous about teaching science because science is a subject that I don't feel confident in teaching as much as the other subjects. I also don't know how well experiments are supposed to be used in science. I am excited to learn some strategies to teach science.

Students have struggled in their own learning experience and recognize the challenge with understanding difficult science concepts. They want to be effective teachers, but realize the need to understand the content and to incorporate effective teaching strategies that they may not have seen as students.

In the initial interviews, students were asked about their attitudes toward teaching science. The results were very similar to the notebook entries. Of the seven students interviewed, two of them spoke only of positive attitudes like being excited and not worried about teaching science. Three students shared that they were nervous, lacked confidence, felt insecure, lacked interest in science, or were not excited to teach science. The two others described a combination of attitudes toward teaching science such as being excited and nervous, or fun with a little fear.

In the mid-study interviews, students had either improved attitudes towards teaching or unchanged attitudes, none reported increased fear or nervousness. The students who were excited about teaching science were still excited about teaching science, for instance, “like I said in my first interview, I love science so it’s not something I’m worried about teaching.” Of the students with negative attitudes, one expressed no real change, positive or negative, for example

I don’t know. I don’t think it’s gotten much more positive, but I don’t think it’s really gotten more negative...it’s a huge subject and I don’t know where I would start and I just think I don’t have good science understanding so it will be difficult but...I guess I’ve seen more ways that you can...give students more understanding in a tactile way.

Two of the students with negative attitudes towards teaching science shared “I think I would feel a little more comfortable teaching it, at least teaching what we have gone over.” and “it makes me feel a little more confident” towards teaching science than before. Of the two students who formerly expressed both positive and negative attitudes, one held the same attitude and the other wrote of being excited to teach science.

Final Attitudes towards Teaching Science

In the final essay, students were asked how formative assessment was helpful to their learning and if they would use formative assessment in their own teaching. I was especially interested in comments that linked the changes in their attitudes with learning formative assessment in the class. One student commented

In the beginning of this half of the semester, we were told to write about how we felt about teaching science. I was honest and said that I was nervous and didn't feel prepared, but by going to class I learned some things that lets me feel more prepared and more confident in teaching science.

Two months after the study, the students from the methods class were emailed the following three questions: How do you feel about teaching science now? Has it changed? If so, what caused the change? Fourteen of the original 24 students responded to the questions. All shared positive comments about improved attitudes towards teaching.

Examples include

I feel that I have been exposed to different ways to think about science and as a learner it was fun to learn without all of the pressure of knowing the terminology. I feel more prepared to teach science in the future, and even though it is not an area that I feel very comfortable in content, using methods to make science fun and hands on instead of taking notes from a lecture are things that I have gained through this class. I really liked the science notebooks to communicate with the teacher any questions that I had over the material, and not having everything graded took a lot of pressure off, for me as a student, because science is an area I struggle with.

Science is still not my favorite subject; however, teaching it isn't quite as intimidating as it used to be I would say. I think it is because we did science curriculum in class, and we did activities that we could do with our own classes at some point. I feel like I have more options, or things to do with my students when teaching science which makes me feel a little more at ease.

At the beginning of this class I don't think I was very confident in teaching science. I knew things about science but just was not sure that I could explain them in a way that my students would understand and that was a fun, educational learning experience for them. After taking the class I feel that I am more confident in my ability to teach science to my students. I am not saying I know everything there is to know about science, because I don't, but that I now have the knowledge of how I might go about teaching a subject to my students and the different resources that I have available to make that teaching happen. I definitely think that this class showed me that teaching a subject (especially science) doesn't mean it has to be the same experience every day/week/year. There is room for growth and change both in the student AND teacher.

It appears that many students showed an improvement in their science teaching efficacy as indicated by the STEBI-B. Compared to the initial science notebook entries, students show the same or improved attitudes towards teaching science. Many of the quotes shown above indicate that the class helped students feel more prepared and confident to teach elementary science. However, I was looking for a connection between formative assessment and this improved efficacy. The students did share about their improved attitudes towards teaching science, but only two made any mention of assessment. Without more students identifying a connection between their improved attitudes and their experience with formative assessment, research question number three remains inconclusive.

Future use of Formative Assessment

Research Question four reads, How can preservice teachers' experience with formative assessment in a science methods class best be designed to enable them to continue addressing their own understanding of challenging science content as well as future students' understandings? My own path of discovery has shaped my appreciation

for formative assessment as I am challenged to improve student learning. Unless a teacher values student learning over content coverage, formative assessment does not provide useful guidance. In my own teaching, it was the challenge of helping students overcome science misconceptions that led me to emphasize formative assessment. This section will present how and why preservice elementary teachers planned to use formative assessment in their own future classrooms. After the study, some of the students began their student teaching. Using data from a post-study interview, this section will also present student teachers' use of formative assessment after the study.

Planning to Use Formative Assessment

As the researcher and instructor, it was exciting to see preservice elementary teachers recognizing the value of formative assessment. In the final essay, each student identified the value of formative assessment and 96% mentioned their desire to use it in their own teaching someday. Many of the students included specifics of how they would use formative assessment as well. The following are excerpts taken from four different students' final essays:

In my own classroom, I hope to use formative assessment all the time. It is very important for me to know how my students are doing. As a teacher it is crucial to know how your students understand what you are presenting to them, and formative assessment is definitely the way to find out. I plan to teach preschool or kindergarten, and some of the formative assessment we have learned about in this class might be too tough for them, but I will collect information from them from worksheets, observations, notebooks, and questioning.

I definitely hope to use formative assessment in my own teaching. I have seen the benefits of formative assessment as a student and as a future teacher. I hope to use some probes and also some open ended questions to see what my students know about the material I will be teaching.

Formative assessment will not only benefit me as a teacher, but will hopefully benefit my students as well.

I do believe that I will use formative assessment in my classroom because every single one of my students is going to have differing levels of knowledge on each subject. Using formative assessment can be a really helpful tool to better understand where exactly each student is at. Just assuming what a child knows already about a subject does not benefit the way we teach or the student's learning. Before this class I did not really like the idea of formative assessment mainly because I thought it was a lot of work and was a boring way to evaluate student's knowledge.

I will definitely use formative assessment in my classroom. I want to make my class a safe place where questions can be asked. I also want to use that information to teach to the students' needs. I might use a combination of entrance and exit slips to decide how well my students are catching on to what I am teaching them. That is one way they can ask questions and I can use those questions to inform my teaching for the next lesson. This has definitely changed as a result of this class, because I did not fully understand formative assessment before. Now I know what it is, and I'm really excited to use it!

The study is limited in that it cannot measure preservice teachers' actual use of formative assessment in their own future classes. Another limitation of this data is that students were submitting this essay to the instructor as part of their final exam and they wanted to make a favorable impression, possibly saying what I wanted to hear instead of their actual intentions. However, the specifics of their intent and the tone of the writing indicate a genuine desire to utilize formative assessment in their future classrooms.

Student final essays also addressed using formative assessment in their own classrooms. In the essays, preservice teachers shared positive experiences about the science methods course, with intentions of using formative assessment in their own teaching. Some mentioned specific tools they would use such as science journals, probes, summaries, concept maps, non-graded quizzes, exit slips, and others. Common reasons given for using formative assessment were to avoid re-teaching content that students

already know, guiding review activities, and to assess the effectiveness of teaching strategies. As preservice teachers experience formative assessment, they recognized its value for their own teaching.

The post-study student interview results reflected similar plans when students were asked about using formative assessment in their own classroom. Here are three responses taken from three different interviewed students:

I have just seen how beneficial it's been to me as a student. I feel like I'm learning new things instead of stuff that I already know...because this formative assessment has shown what we do know and what we don't know and so as a teacher I want to use that and ...be able to have my students show me what they know about a certain subject...so that we can avoid teaching stuff they already know and go right to teaching stuff that they don't know, hopefully it will guide my instruction.

I value formative assessment more, so it will be something I will consciously put into each unit...Even though it seems like formative assessment just creates more work sometimes, it is worth it for the students' learning and understanding of material. It's also a way to evaluate things that I could do better or things that I should leave out.

I think that being able to actually watch someone do FA and make it clear that that's what it is that they're doing will help me to think about ways that I can implement that into my classroom. I know that like in lots of different classes we take quizzes or do worksheets and things like that but to actually see someone doing it and to hear them say this is why I'm doing this formative assessment, it really helps for me to think, okay, this is how I can do it in my own classroom and this is why I would do it in my own classroom.

Student Teachers Using Formative Assessment

After the study was completed, some of the students began their student teaching. Recognizing that preservice teachers' aspirations may or may not make it into the classroom, it seemed prudent to collect follow-up data on how formative assessment was, or was not, implemented during the student teaching experience. In the middle of their

field experience, ten student teachers agreed to respond to my questions. Seven of the student teachers were available for a personal interview, three of the students responded to questions via email. Six of the 10 student teachers were from the study class, while four were from a previous class, allowing me to explore comparative possibilities between the two groups. The student teacher placements included special education, kindergarten, and 2nd through 5th grade classroom instruction.

To begin with, there were some interesting general patterns in the data. For instance, each of the student teachers recognized a need for using formative assessment in their teaching. Examples included, “I just felt there was a need to do a formative assessment prior to going into any of my lessons” or “Yeah, I thought it was very helpful for me just to know what to teach and what not to teach.” Seeing a need for formative assessment did not guarantee that student teachers actually used it. Of the ten responders, three did not use formative assessment. One of those students was from the study and the other two were not. The reasons given for not using formative assessment were time, “I think it’s a good tool, it’s just really hard to implement when you’re on a time schedule”, and lack of importance, “I definitely see the value in it, but it did not seem important in my first student teaching experience.”

Of the students who did use formative assessment, there were a variety of explanations. Students made reference to their experience in my class, “your class is really the first time I was taught formative and summative. That has connected with me; something that I definitely took from your class is the formative assessment.” Another student said

I started thinking back to teaching science and social studies and about formative assessment and thought that was the best way to go with this situation. I liked the idea of formative assessment when I was learning about it at (the institution of the study), and now I feel like I have been able to try it out myself.

Some students mentioned doing activities they had seen their cooperating teacher do.

These sometimes involved diagnostic or formative assessments accompanying specific district-adopted curricula: “I gave the Saxon test a few times, I gave the reading test a few times” or “They do that every five days actually; in their Saxon Math.” And some students mentioned other experiences from their teacher preparation:

I guess the program has taught me to be observant of my kids and to notice if they don’t understand. This just leads to formative assessment in all honesty. It is hard to teach how to “do” formative assessment until you get put in that position, then you just do it.

I can remember learning about exit slips with (another methods instructor) in one of her classes. I mean on the day that she taught it, I remember we had to do an exit slip.

Different sources of learning about formative assessment provide different expressions within the classroom. It was exciting for me to see ownership and “buy-in” among so many student teachers.

As these student teachers implemented formative assessment in their classrooms, each student provided unique reasons and applications. Some of these perceptions could be connected back to data collected during the study. For instance, in her final essay, one student wrote, “For me as a student, using the probes and group concept maps were the most effective formative assessments for me.” This same student shared how she designed her own probe-like worksheet to see what students understood about vowel sounds. When relating her purpose for using formative assessment during the course, one

student explained that she would use formative assessment because it would waste less time by not teaching material that students already knew. However, during her student teaching, the same student struggled to find time to use it saying, “I think it’s a good tool, it’s just really hard to implement when you’re on a time schedule.” A third student described in her essay that it was “very important for me to know how my students are doing.” During her student teaching, she described the realization that her students did not appear to learn the material from her lesson on amphibians. “I had no idea that they didn’t catch it. I had no idea that they didn’t know.” This realization provided purpose and focus for improved questioning and additional review activities with her students. In summary, the data collected during the study did not provide any noticeable predictive capabilities for students during student teaching. However, comments made during the student teacher interviews showed unique patterns and choices that related back to their thoughts during the class. It was most interesting to see how each student had molded their experiences from the science methods class into their own thinking which was then expressed through the student teaching experience.

Recognizing that each student teacher had their own reasons for using formative assessment, I asked them why they chose to use it during their student teaching. The student teacher interview responses can be grouped into five reasons that they used formative assessment: differentiating instruction, effective planning, reducing overlap, guiding review, and seeing student understanding. Table 4.15 provides some examples of why student teachers use formative assessment to guide their instruction in the classroom.

Table 4.15. Student Teacher Interviews Provide Reasons for Using Formative Assessment.

Reasons	Examples from student teaching
Differentiated instruction	<p>And there were those kids that caught right on and I could tell that they needed to go forward. And there were some kids that still needed practice... We would check over their worksheets from the day before and see who gets this and okay they need to move on to three digits. They need to play this game and that will help them have more practice with it. And who still needs more practice and then we would have them fill out more games or more worksheets or whatever they needed. And then who needs this retaught and then I would sit with a group of kids at the end of the lesson and then completely start over again... So I guess that is a type of formative assessment, looking at where everyone was at and then re-teaching or going on or staying. (2nd grade)</p>
Effective planning	<p>I just felt there was a definite need to do a formative assessment prior to going into any of my lessons, just to see, because I for one didn't know where these kids were coming from on their knowledge of animals in the winter... And I remember with math doing some type of activity, after the lesson to make sure, ok, is this something that we need to revisit tomorrow to make sure they understand how to re-group, and go from tens to ones, and that kinda stuff and making sure that they have the knowledge that we need in order to move on to the next day. (2nd grade)</p> <p>I needed to find out where to start- and to know where to start, I thought I'd better find out what my students do and don't know. (Special education)</p>
Reducing overlap	<p>If you know what students already know, you don't have to spend time re-teaching it and you can actually teach them more, and you know the knowledge will be deeper on the subject matter (Kindergarten)</p> <p>But I was ready and willing to modify and change depending upon what they knew; you don't want to bore the kids with something they already know (2nd grade)</p>
Guiding review	<p>That's just in math, but there's definitely a need for it because then you can see what they need to review (2nd grade)</p> <p>I need to change my teaching. I need to change something. I need to review something again (Kindergarten)</p>

Table 4.15 Continued.

Seeing student understanding	I always thought it was kind of important to see where students are at. (4 th grade) Formative assessment is used so you can know what kids know. (Kindergarten)
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The student teacher interviews provided confirmation that formative assessment was making it to many classrooms after this study. Of the six student teachers who participated in the study, five of them incorporated formative assessment into their student teaching experience. One student designed her own probe, “For language arts, I did a formative assessment on short vowel sounds by creating a probe-like worksheet to see what the students understood.” Another student teacher incorporated little quizzes, “The way I used that was through questioning throughout the lesson, through bell ringers, through little quizzes like you had us do as well.” It appears to me that most of these student teachers, not only learned a variety of methods for implementing formative assessment in the classroom, but they also recognized the value it provides for student learning. This combination seems to provide a memorable experience that transfers to their next teaching experience.

Student Learning of Challenging Science Content

Did the study improve preservice teachers’ ability to learn challenging science content? It was difficult for students to answer this question. When asked in the student interviews, most of the seven students avoided the question or did not really answer it at all. For instance, when asked “How has this experience changed your ability to learn challenging content?” one student replied, “there’s always something new that you can

learn about something ...you have to be patient with your students”; another proclaimed “I have a lot better understanding of photosynthesis than I did”. Two students did not answer the question. One reflected on the importance of relating the difficult material to students’ lives and the other shared, “it takes longer than I thought it would, I mean, if it takes me that long, how long is it gonna take the kids?”

The data did not show evidence of improved strategies for preservice teachers’ own learning of difficult science content. The preservice teachers connected formative assessment to teaching, but not everyone recognized a connection to their own learning of challenging science content.

Summary: Future Use of Formative Assessment

Teachers in many schools are being encouraged to incorporate formative assessment into their classrooms. The biggest struggle may be for teachers to appreciate the value of formative assessment to further student’s self-awareness of their knowledge, including areas of stronger or weaker understanding, so that they can take ownership for their own learning. The preservice teachers in this study grasped the importance of formative assessment as a tool for teachers’ use when fine-tuning instruction and some were beginning to appreciate the importance of sharing formative assessment results with students. The students from this study indicated that they recognized the value of using formative assessment in their classroom and desired to incorporate it in their own classrooms. The final interviews showed that some students have already incorporated formative assessment strategies into their student teaching experiences. As they become classroom teachers, my hope is that the participants in this study will continue to work

out effective methods to explore student understanding and will increase communication with their own students about the learning of science.

CHAPTER 5

DISCUSSION

The interest of this study was to explore effective ways to teach science methods to preservice elementary teachers that also helps students overcome some of their science misconceptions. My desire was to implement formative assessment as a methodology for overcoming science misconceptions that could achieve two different goals; 1) identify and overcome science misconceptions held by the preservice teachers while also 2) implementing and experiencing formative assessment as an effective instructional/learning method that preservice teachers could bring to their own science classrooms. Earlier attempts to confront student misconceptions appeared to increase science anxiety and reduce science teaching efficacy, already a concern with this particular group of learners. Employing instructional tools to identify student misconceptions caused me to wonder how many science misconceptions are deeply held by students versus apparent misconceptions resulting from incomplete knowledge, lack of experience, or lack of interest.

Formative assessment is a methodological tool that is used to explore student understanding. Could formative assessment be used to identify specific science misconceptions held by students? Could formative assessment identify specific gaps in knowledge that students need to overcome? The purpose of this study was to conduct a design experiment that would utilize various types of formative assessment in an elementary science methods classroom to identify science misconceptions held by

students, to reveal incomplete knowledge, and to demonstrate the use of formative data to guide instruction.

Indications of a successful design would show that students were able to overcome apparent misconceptions and to demonstrate increased understanding of the science topics addressed. Students would also demonstrate increased understanding and appreciation for formative assessment as a useful teaching tool. In comparison to confrontational approaches towards science misconceptions, students would develop improved attitudes towards learning and teaching science in the elementary classroom.

The results demonstrate that some of the goals were met. Students did increase their understanding of both science content and formative assessment. The formative assessment tools were able to identify some of the missing knowledge that students needed to learn. This formative data was used to guide content instruction in the classroom. However, addressing the incomplete knowledge of students did not resolve all of their misconceptions. For example, with the first topic, plant food and photosynthesis, many students still held part or all of their misconceptions, even at the end of the study. The persistence of this apparent misconception through instruction would cause me to identify it as a deeply held misconception. Obviously, the missing knowledge obtained in the classroom did not resolve the misconception and other instructional strategies would need to be used. It may be that these students are unmotivated to learn this difficult topic, in which case motivational issues would need to be addressed. Also, it may be necessary to consider other strategies, such as cognitive dissonance, to help student realize they need to adjust their understanding.

With the second topic, plate tectonics, students began the intervention with very little prior knowledge. At the end of the study, students had gained considerable understanding and felt confident in their learning accomplishments. It would seem that students find new material easier to learn. However, the students may be correct in their claims that learning about plate tectonics was just easier than learning about plant food and photosynthesis.

Science methods classrooms, groups of students, and learning experiences are not the same. Recognizing that each student is unique can motivate teachers to consider a variety of learning preferences. However, it also appears that each science misconception is unique enough to necessitate different instructional considerations as well. While learning about plate tectonics, identifying gaps and trying to fill them worked as a teaching strategy. However, in the case of plant food and photosynthesis, it appears that some science misconceptions were deeply held, and different strategies should have been considered. Maybe different connections needed to be made, maybe some gaps in their understanding were overlooked, maybe students did not see the topic as important to them, maybe they needed to find dissatisfaction with their incorrect understanding, or maybe I needed to be more confrontational in my approach. These are the questions that challenge my teaching and provide me with endless opportunities for continual improvement in my teaching.

In this study I was also sensitive to the efficacy of my students. It was rewarding to see students' increased confidence in their ability to teach science as seen through the results of the STEBI-B and their comments in student interviews and student essays. Through these same essays and interviews, students expressed a strong desire to use

formative assessment in their own future classrooms. It appears that they recognized the usefulness of this strategy which can help identify specific gaps in student understanding, and help guide instruction for overcoming some apparent student misconceptions in science.

Reflections on the Methods

Before the study began, the structure and data sources of the study were determined. As the study progressed, adjustments were made to improve student content understanding and the use of formative assessment in the classroom. This section will reflect on the study and explore what was particularly effective and what could have been done better. In the paragraphs below, I will briefly explain selecting the diagnostic tool, choosing formative assessment tools, applying formative assessment data to guide instruction, conducting student interviews, and the role of the instructor/researcher.

The diagnostic tool used to determine the science content topics provided a valuable window into student understanding. Creating the tool on the AAAS website (American Association for the Advancement of Science, 2011) required minimal learning time, provided flexible options, and covered a wide range of science topics. After presenting the survey results, students confirmed that plant food/energy and plate tectonics were challenging topics to them personally. More recently, I have utilized the same diagnostic test with a different group of students with different results. Using the same survey, two science topics were most challenging; one was the same, and the other was different than the topics determined for this study. This variation suggests that the diagnostic tool did provide unique results for a unique group of students.

During the intervention, one of the challenges was to choose which formative tools to use. Recognizing that different tools provide different data, I started with tools that identified student misconceptions. Some tools, like the diagnostic survey (American Association for the Advancement of Science, 2011) and formative assessment probes (Keeley, 2011), easily identify student misunderstandings. However, these tools were insufficient for identifying students' missing or incomplete knowledge. Students were asked to explain their answers on the probes, but it was hard to decipher from very short or missing explanations. Seeking to identify gaps in students' knowledge led me to explore small group concept maps, non-graded quizzes, and a short answer pretest. Students used the process of constructing concept maps (and non-graded quizzes) to identify their own questions or areas of confusion. Students recognized the importance of formative assessment when they saw their questions guiding instruction, for the edification of both teacher and students.

In some cases it was easy to show how the data was used to guide instruction. For instance, the data from the diagnostic tool provided me with two science topics to teach during the intervention. Recognizing that students' first attempt at concept maps were unsatisfactory led to additional instruction on how to create a concept map. Using group concept maps to help generate student questions about photosynthesis provided guidance for the next lesson on photosynthesis.

It was more challenging to know how to use data from the formative assessment probes. For instance, the food probe (Table 4.4) showed that only four students identified milk, ketchup, sugar, syrup, butter, or flour as an item scientifically called food. The most common reason given by students was that these items are not eaten alone. What

should a teacher do with this data? Should students be told their answer is wrong? Will writing down the definition of food improve their understanding? Have they been told this before? In this instance, I tried to connect human food with plant food via a shared understanding of producers (make their own food) and consumers (eat their food). If both types of organisms relate to the same concept of food, what characterizes the food produced by plants and consumed by animals? Looking back, I could have asked students what experiences they have had with plant food and tried connecting to their prior knowledge. However, if my purpose for eliciting additional prior knowledge is only to refute it, students will stop answering questions. Looking back, I could have encouraged students to talk about this issue with a partner. Maybe, as they explained their understanding of food to each other, they would improve their understanding. Overall, using formative assessment to identify missing or incomplete knowledge provided clearer guidance than previous efforts to confront student misconceptions.

Student interviews were included in the study to compare student content understanding to the formative assessment results and to hear individual preservice teachers' reflections on their learning experiences with formative assessment. The seven students selected were cooperative and gave generously of their time for three different interviews. Before each set of interviews, I practiced using the interview guide with my research assistant. Interview responses were triangulated with formative assessment data, providing further insights into student understanding. For example, the interviews confirmed that students were learning the science content and appreciated the use of formative assessment. The interviews also provided an opportunity to hear what individual students were thinking. I had never asked students these questions as

individuals and it was interesting to hear their perspectives on learning in my classroom. In retrospect, individual student interviews might be the best example of formative assessment. All other formative assessment instruments are an attempt to develop effective communication about each student's learning without investing the time required to interview each student.

A unique experience for me was to participate in the study as an instructor and as the researcher. I have spent 18 years as a classroom instructor. I have never conducted publishable research in my classroom. While teaching is always a learning experience, this was another level of learning. In addition to designing instruction, I learned how to design the study, design data collection tools, create interview guides, conduct interviews, process results, and communicate results. I made mistakes and learned from them. I wrestled with deciding what data best represented the experience and how to present it. I struggled with wanting more data, and not knowing what to do with the data I had. As I read other case studies from the classroom (Rice & Roychoudhury, 2003), I appreciated learning from their experience. This motivated me to clarify and communicate my own experience for the benefit of other methods teachers as well.

Reflections on the Literature

After the data collection and analysis, it seemed prudent to reexamine some of the literature and reconsider the findings in light of the experience. Specific areas included design research, science misconceptions, conceptual change, and formative assessment.

Design research emphasizes the importance of connecting research to the classroom. Research informs an educational theory and that theory informs classroom

practice (Lesh, Kelly, & Yoon, 2008). In this study, the educational theory combined formative assessment methodology with science content instruction in a science methods classroom. The emphasis on student learning within the complex, messy context of the classroom (Collins, Joseph, & Bielaczyc, 2004) provided a practical backdrop for the intervention. The intervention itself provided cycles of design and implementation as formative data guided subsequent instruction (Gravemeijer & Cobb, 2006). Consistent with other design research, the results of this study did not provide simple answers or a tested hypothesis. Instead, the product was related conceptual tools whose success was determined by their usefulness in the classroom (Lesh, Kelly, & Yoon, 2008). However, as is typical of design research, it is difficult to know what combination of features actually contributed to its success (O'Donnell, 2004).

The fact that many of our students hold misconceptions in science is undeniable. A variety of diagnostic tools have been developed to help teachers identify students with particular misconceptions (Appendix C). Formative assessment probes (Keeley, Eberly, & Farrin, 2005) have also been designed to identify student misconceptions for the purpose of guiding instruction. In diSessa's (2006) assessment of the misconceptions movement, he recognized ambiguity in defining what determines a misconception. I also experienced this ambiguity with the diagnostic tools; they made no distinction between a deeply held misconception and missing or incomplete knowledge. Implementing other formative assessment tools to identify missing knowledge demonstrated that many of the students' "misconceptions" in science were, in fact, cases of missing knowledge. I found that using this missing information to guide instruction in the classroom was more clear-cut than my attempts to address deeply held science misconceptions. Students in this

study still held misconceptions about plant food through the final quiz. Once a teacher realizes that students hold onto a science misconception after instruction, then it would be prudent to try some of the other instructional strategies suggested by the conceptual change literature and listed in Chapter 2. The focus of this study was on using formative assessment to explore student understanding. Although a variety of instructional strategies were also used, they were not the focus of data collection. Most instructional decisions considered the research, but were made based upon my own previous teaching experience. This complexity goes hand-in-hand with classroom research.

In the case of a deeply held science misconception, students need to undergo a conceptual change. This implies that students' prior knowledge is a negative condition that needs to be fixed (diSessa, 2006). Early conceptual change research encourages teachers to replace the incorrect prior knowledge with correct scientific knowledge (Chi, 2008; Stepan, 1994; Strike & Posner, 1985; Vosniadou, 2007a). In this study, I learned that some, but not all, of students' identified misconceptions could be addressed as missing or incomplete knowledge. For instance, as students communicated gaps in their understanding of plate tectonics, I was able to focus my instruction to provide missing knowledge, and most of the students overcame their misconceptions. I did not confront incorrect explanations, nor did I provide especially convincing scientific evidence. This suggests that sometimes our instructional approach toward science misconceptions could be more of an enrichment of student understanding than a replacement of student understanding (Clement, 2008; diSessa, 2006; Linn, 2008). The variety and lack of agreement in conceptual change research gives credence to the complexity of student learning. Taking into consideration preservice elementary teachers' self-efficacy,

motivation, and engagement in science, the enrichment approach towards overcoming student misconceptions has an attractive sensitivity that might be lacking in a replacement approach.

Based upon my experience as an instructor and student comments from the course, formative assessment provided a valuable tool for teacher-student communication. During the study I learned that students appreciated opportunities to generate content questions. As one student commented after class, she thought students enjoyed submitting anonymous questions about science content. Comments from student interviews indicated that it was helpful to use a non-graded quiz or a group concept map to help students generate questions directly related to the science content learning goals. A similar study using formative assessment suggested that “preservice teacher education should guide teacher candidates in recognizing the value of the students’ conception as knowledge-in-information, rather than simple misconceptions” (Buck, Trauth-Nare, & Kaftan, 2009, p. 405).

My students confirmed that experiencing formative assessment to improve their own science understanding was instrumental in recognizing its value for the classroom. These mindsets towards student misconceptions can motivate teachers to use formative assessment, helping students connect their correct knowledge and experiences to scientific understanding (Otero & Nathan, 2008). I recognized that each teacher must find his or her own way to incorporate formative assessment into their teaching (Black & Wiliam, 2003). However, with the limited time available to them, teachers are less likely to implement formative assessment as a concept, if they have not seen/experienced how it might look in practice (Black, Harrison, Lee, Marshall, & Wiliam, 2009). With this in

mind, I was less concerned with providing prescribed implementation and more interested in improved communication. It guided my intentional effort to make “the students’ voice louder and the teacher’s hearing better” (Black, Harrison, Lee, Marshall, & Wiliam, 2009, p. 59).

Science misconceptions, knowledge gaps, conceptual change, formative assessment and their interrelationships were central in the design of this study. Taking into consideration such factors and the variety of relevant teaching strategies can be overwhelming when designing a science methods course. With limited instructional time, I was constantly making decisions and judgments concerning curriculum and daily instruction. The four goals for my methods course were to help preservice teachers develop “(a) a theoretical framework for teaching science at an elementary level, (b) a repertoire of methods for teaching science, (c) favorable attitudes towards science and science teaching, and (d) deeper understanding of some science content areas” (Morrison, McDuffie, & Akerson, 2003, p. 7). Part of my theoretical framework was an emphasis on student understanding using formative assessment as the method. Student essays and interview responses suggest that most students experienced deeper understanding of the two topics and improved efficacy towards teaching science.

Implications

Preparation of effective teachers must include knowledge of the learning process and skills for collecting information on students’ prior knowledge (Darling-Hammond & Bransford, 2005). Broadly supported goals to improve student learning and teacher accountability have driven issues of assessment into the forefront of the education

agenda. Although all of my students anticipated using assessment as an evaluative tool, incorporating assessment to improve student learning and effective teaching was less well perceived. Formative assessment provides instruments to improve communication between students and teachers to increase the effectiveness of classroom instruction. Although formative assessment was familiar to the preservice teachers in my classroom, they had limited experience incorporating it into their own learning or teaching. Teacher preparation programs need to recognize this need and incorporate effective ways for new teachers to embrace assessment for learning.

Recommendations for Elementary Science Methods Instructors

In my dual role as researcher and science methods instructor in this study, I attempted to provide insights for science methods instruction. Teaching science methods to preservice elementary teachers involves more than just explaining a list of teaching strategies. Guided by the goals mentioned above, this study provides some insights into science methods for preservice teachers, formative assessment, and the value of student-teacher communication.

Science notebooks were used to better understand preservice elementary teachers. The first assignment in the science notebook was to define science and to explain how students felt about teaching science. Only a few of the students' entries were positive about teaching science. Although some entries were mixed, almost half of the preservice teachers were primarily negative in their comments about teaching science. These attitudes were not visible on their faces, but collecting the notebooks confirmed these attitudes and reminded me that learning science has not been a great experience for many

of these students. As methods instructors, we need to see beyond the smiles and nods that successful students have learned to perform and realize that many of the students in our science methods class do not want to or are afraid to teach science. In response to this reality, methods teachers need to provide successful science content learning experiences for our students. If the recently released draft of the *Next generation Science Standards* (Achieve, Inc., 2012) is adopted, preservice teachers can be shown the actual science standards for each grade level. This could provide additional guidance for science content instruction in the methods classroom.

Preservice teachers come to class with limited prior knowledge about science and how to teach it. Writing answers to the question “what is science?”, only one of my students emphasized science as an experimental process. Reading my students’ limited definitions of science confirmed my decision to emphasize the process of science, develop science skills, and provide a variety of engaging learning activities within my science methods course. My recommendation here is not that all methods teachers need to emphasize the process of science (although that may be necessary), but we need to learn what our students do not understand well, and use that knowledge to guide our instruction. Different formative assessment tools can provide different guidance for instruction. For instance, concept maps may be helpful to see individual student connections or they could be used to generate small group questions about photosynthesis. It was hard for me to use 24 concept maps to guide instruction, but the group questions provided more concrete direction for my lesson content.

If I want my students to collect student data to explore understanding, then I should be doing it as well. Preservice elementary teachers need to recognize that we

sought out and heard their voice, for the purpose of providing effective instruction in the classroom and not always for evaluative purposes. At one point I wanted to present an outline of my target goals for learning photosynthesis. Instead of creating a power point of the information, I turned the key points into a non-graded quiz, with peer discussion between each question. After the quiz, instead of a score, I asked students to submit the questions they had about the material. In subsequent writing, one student remarked that she had never considered giving students a quiz without a grade; that she had never considered the value of ungraded assignments to enhance student learning.

Formative assessment is not attractive to all teachers. With limited instructional time, each teacher must overcome barriers to incorporate a new strategy into his or her classroom. As I was challenged by student misconceptions in science, I realized that effective teaching was more than topic coverage and engaging presentations. However, if my goal was student understanding, I realized that I needed to consider what was happening inside students' heads. With this renewed interest in student learning, other questions arose, such as, which teaching strategies are most effective for student learning? As I considered using formative assessment, other questions arose: Will the addition of formative assessment be worth the lost instructional time? Is effective to use formative data to disrupt the lesson (or unit) plan? How should I collect formative data? How should I use the data to improve instruction? How will I know if formative assessment really makes a difference in student learning? I continue to question myself about how to apply formative assessment effectively. However, I appreciate the guidance from Black and Wiliam (2003) that each teacher must find his or her own way to incorporate formative assessment into their teaching. This is true for the methods

instructors as well as preservice elementary teachers. I am still finding my own way, but based upon this learning experience, incorporating formative assessment in my science methods class continues to be worth the challenge.

Recommendations for Professional Organizations for Science Teachers

Regional and national organizations for science teachers such as NSTA provide a variety of publications to improve and increase the use of classroom assessment. Recent titles include, *Seamless Assessment in Science: A Guide for Elementary and Middle School Teachers*, *Assessment in Science: Practical Experiences and Education Research*, *Everyday Assessment in the Science Classroom*, and *Uncovering Student Ideas in Science*. With this emphasis on assessment, such organizations must continue to identify programs with effective implementations of formative assessment and communicate this information to and between science methods instructors. Also, if elementary teachers are using formative assessment in their teaching, what caused them to embrace it, how did they learn to implement it, and how did they make it effective for learning?

In the *Standards for Science Teacher Preparation* (NSTA, 2003), Standard 8 is entitled “Assessment” with subcategories that ask for teachers to use multiple tools for assessment, use the results to guide and modify instruction, and use results as vehicles for students to engage in reflective self-analysis. I struggled with how to specifically use the formative data I collected to guide instruction. In my conversations with elementary teachers, they also struggled with what to do with collected formative data. Recognizing that teaching is complicated and messy, I recommend continued discussion between elementary teachers and methods instructors especially in this area of incorporating

student data into guiding instruction. Based upon this study, I think a good first step is to use formative assessment to identify gaps in student understanding and then reteach to those specific gaps. I think it takes a more experienced teacher to implement cognitive conflict or to confront student misunderstandings. This study has also shown that students' apparent science misconceptions can sometimes be addressed by addressing gaps in understanding without resorting to confronting students' incorrect ideas. With increasing availability of tools for detecting student misconceptions (such as the Keeley probes), future articles could reflect a distinction between apparent student misconceptions in science and deeply held science misconceptions and suggest appropriate instructional strategies for each.

Recommendations for Science Content Instructors

The just-released draft of the *Next Generation Science Standards* (Achieve, Inc., 2012) provides guidelines for science content for each grade level. The preservice teachers in my methods course were challenged by the amount of science content they are expected to understand. They also perceived disconnect between introductory college science courses and elementary science teaching. In introductory science content courses, instructors need to recognize that they are preparing elementary teachers to bring science to the children of society. Efforts must be made to engage preservice teachers in the process of science and to teach for student understanding of science content.

As the new national science standards are implemented, the shift should continue towards students' deep understanding of essential material rather than massive content coverage. Without this shift in educational purpose, there is a tendency to measure

success by the number of chapters covered instead of the depth of student learning. Science content instructors need to seek out effective teaching strategies to increase student understanding. As formative assessment increased, my knowledge of my students' understanding increased, and so did the effectiveness of my classroom instruction.

Having accepted the premise that formative assessment improves student understanding, the challenge is finding multiple ways to incorporate formative assessment into the classroom. Although this study took place in a science methods classroom, the implementation involved learning science content while using formative assessment. Any science class instructor could utilize formative assessment to explore its effectiveness for student learning, preferably without it always affecting students' grades.

Suggestions for Future Research

Although this study provided confirming evidence of the benefits of formative assessment in a science methods class, there are still unanswered questions and opportunities for further research.

Finding and filling the gaps of student understanding did not resolve all of my students' misconceptions about plant food. However, we must be sensitive to the science efficacy of elementary preservice science teachers. In light of this study, as well as research by others (Limon, 2001; Zohar & Aharon-Kravetsky, 2005), I suggest further exploration into addressing apparent science misconceptions as incomplete knowledge, and to save cognitive conflict for deeply held misconceptions. Additional research should explore the relationship between science efficacy and confronting deeply held

science misconceptions. I wonder if sequencing science instruction would be more effective if instructors started by using formative assessment for identifying and addressing incomplete knowledge, and then resolving students' deeply held misconceptions as they persist through instruction.

Preservice elementary teachers want their students to feel cared for. In this study, one student stated that her experience with formative assessment made her “feel more cared about and valued as a learner. It [formative assessment] makes me feel as though the teacher is genuinely interested in what I am learning and the progress I am making” (Student Essay). This is worthy of further study. If it can be confirmed that formative assessment conveys caring to students, then a follow-up study could explore whether this connection might influence elementary teacher acceptance of formative assessment and motivate others to implement it as well.

Another topic for study concerns the motivational aspects for implementing new teaching strategies. Issues of motivation can complicate both learning and teaching. Three traditional indicators of behavioral motivation include: choice of task, level of engagement, and willingness to persist (Pintrich, Marx, & Boyle, 1993). What factors influence teachers to change their teaching practice? Is dissatisfaction with his or her instructional model the best motivator for change? In this study, preservice teachers appeared motivated to incorporate formative assessment into their teaching. Further study would be needed to identify both the factors influencing that desire and the depth of that commitment.

Continued Learning

Design research suggests a cycle of improving practice and learning through implementation and reflection. The challenge of teaching and learning science methods for elementary teachers continues. I will continue to use formative assessment probes, group concept maps, and non-graded quizzes to improve communication, to identify student missing knowledge, and to guide my instruction. I will try to improve our communication with science notebooks by asking for more student reflections and by assigning more short answer responses. I intend to explore student experiences and their relationships to content knowledge. For instance, what experiences do students think of when asked about plant food?

During the study, I used formative assessment probes as a tool to collect data on student understanding. Attempting to keep the data pure, I collected the probes and limited discussion with peers. Based upon previous years, formative assessment probes are great tools to initiate conversations between students. In future semesters, I will increase time for student interaction in relationship to the probes. Some probes will be collected, others left with students to consider and process with each other.

Given pressing demands on teachers' time, it becomes impractical to conduct student interviews outside of the class, but I may try to interview students during class to model questioning skills and explore students' prior knowledge. Or I could have students interview each other in pairs, identify incomplete understanding, and design appropriate instruction. With or without interviews, I will continue to seek ways to hear what my students think about a science topic and to encourage them to listen to each other as well.

In the anonymous student course evaluations, the strongest negative comments suggested that learning about photosynthesis had nothing to do with teaching methods for elementary science. Next semester, this connection between content learning and teaching needs to be explained clearly to students who might be frustrated with learning science content in a methods class. The final essays also reflected some of this frustration, and the writers seem to come disproportionately from early childhood preservice teachers. As I address hard concepts in science, I need to include examples and connections for early childhood instruction as well.

In future classes, I want to improve my ability to interpret data and use it to guide instruction, while also listening to student suggestions. For example, this past semester a student asked to see her initial formative probe to compare her previous understanding with improved understanding. As the class looked at their prior knowledge, they were able to see evidence of what they had learned. I realize that creative solutions will only arise as I am willing to try new possibilities, make some mistakes, and confirm what works. In my next phase, I seek to incorporate the *Next Generation Science Standards* into the course content; explore ways to confront deeply held science misconceptions; and further explore the implementation of science notebooks, concept maps, formative assessment probes, and discrepant events. I encourage all instructors to make their students' voices louder and their own hearing better (Black, Harrison, Lee, Marshall, & Wiliam, 2009) as we continue to improve our use of formative assessment and the effectiveness of science instruction.

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APPENDICES

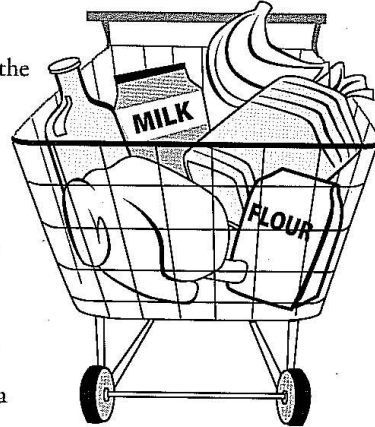
APPENDIX A

SAMPLE FORMATIVE ASSESSMENT PROBES

Is It Food?

What kinds of things are considered food? Check off the things on the list that are scientifically called food.

- | | | |
|---------------------------------------|--|---------------------------------|
| <input type="checkbox"/> lettuce | <input type="checkbox"/> sugar | <input type="checkbox"/> salt |
| <input type="checkbox"/> cookies | <input type="checkbox"/> bread | <input type="checkbox"/> butter |
| <input type="checkbox"/> milk | <input type="checkbox"/> vitamins | <input type="checkbox"/> water |
| <input type="checkbox"/> french fries | <input type="checkbox"/> candy bar | <input type="checkbox"/> turkey |
| <input type="checkbox"/> minerals | <input type="checkbox"/> pancake syrup | <input type="checkbox"/> banana |
| <input type="checkbox"/> ketchup | <input type="checkbox"/> diet soda | <input type="checkbox"/> flour |



Explain your thinking. What definition or "rule" did you use to decide if something can scientifically be called food?

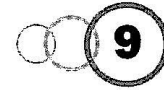
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Keeley, P., & Tugel, J. (2009). *Uncovering Student Ideas in Science: 25 New Formative Assessment Probes Vol. 4*. Arlington: NSTA Press.

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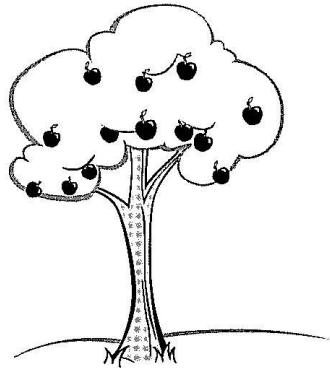
Sample Formative Assessment Probe 2



Structure and Function

Apple Tree

Six friends were picking apples. They each had different ideas about where the apple tree makes the food it needs to live and grow. This is what they said:



Molly: "I think the food is made in the tree's roots."

Joan: "I think the food is made in the leaves of the tree."

Bonnie: "I think the food is made in the apples the tree produces."

Bev: "I think the food is made in the tiny tubes in the trunk and the branches."

Susie: "I think the food is made in the apple blossoms."

Jared: "I disagree with all of you. I don't think apple trees make their own food."

Which friend do you agree with the most? _____ Explain why you agree.

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APPENDIX B

DIAGNOSTIC TOOLS AVAILABLE
FOR IDENTIFYING PRESERVICE TEACHER
SCIENCE CONTENT MISCONCEPTIONS

Test Name	Subject areas	Comments
AAAS Science Assessment http://assessment.aaas.org 2011 (American Association for the Advancement of Science)	Life - cells, evolution, human body, ecosystems, energy in living systems, heredity Physical- atoms, molecules, states of matter, energy, force and motion, chem. reactions. Earth- plate tectonics, weathering, erosion.	Varying number of questions for each area. Test constructed online with the teacher selecting topics. Questions have been pilot tested and field tested on a national sample.
ATLAST Horizon Research Inc. 2008 (Assessing Teacher Learning About Science Teaching)	Force and Motion Plate Tectonics Flow of Matter and Energy	Well-designed questions with separate assessment tools for teachers and students. Limited topics. 30 questions each.
Diagnoser Project http://www.diagnoser.com 2010	Physics – force and motion, waves, sound, light, matter, heat, particulate nature. Chemistry – atomic structure, bonding, reactions. Human Systems – digestive, circulatory, respiratory.	Online assessment and teaching tool. Teachers can set up a class with student access codes to track progress. Questions and feedback provide students with a short unique learning experience.
DTAMS (Diagnostic Science Assessment for Middle School Teachers) University of Louisville	Physical – matter, motion, forces, energy. Life – structure, function, heredity, regulation. Earth – atmosphere, tectonics, geology, space	20 questions for each of the three tests. Designed for teachers. Test is free, but analysis of results costly at \$10 per assessment per teacher.
Force Concept Inventory	Physics – Force and Motion	In-depth analysis of the topic. Used in physics classes.
MOSART (Misconceptions Oriented Standards-based Assessment)	Astronomy -- K-4, 5-8, 9-12 Earth -- K-4, 5-8, 9-12	Designed for diagnostic or pre/post instruction for three different grade levels.

Resource for Teachers)

Physical -- K-4, 5-8
Life -- K-4, 5-8 (new in
2011)
Physics 9-12
Chemistry 9-12 (new in
2011)

13-25 questions per test.
Developed as a follow-up
to the Private Universe and
Minds of Our Own.

APPENDIX C

AAAS SAMPLE TEST QUESTION WITH GRAPHS

AM039004

What happens when a cup of water is warmed?

- A. The water molecules break down.
- B. The number of water molecules increases.
- C. The mass of the water molecules decreases.
- D. The distance between the water molecules increases.

[AM039004] The distance between water molecules increases as a cup of water is warmed.

Distribution of responses

Answer Choice	Overall	Grades		Gender		Language	
		6–8	9–12	Male	Female	Primary Language is English	Primary Language is <i>not</i> English
A. The water molecules break down.	17%	19%	14%	16%	19%	17%	25%
B. The number of water molecules increases.	20%	24%	13%	19%	21%	19%	22%
C. The mass of the water molecules decreases.	17%	19%	15%	17%	17%	17%	21%
D. The distance between the water molecules increases.	45%	38%	58%	48%	43%	47%	32%

TOPIC

Atoms, Molecules, and States of Matter

IDEA

For any single state of matter, increasing the temperature typically increases the distance between atoms or molecules. Therefore, most substances expand when heated. (from 4D/M3)

CORRECT ANSWER CHOICE

D

MISCONCEPTIONS**ANSWER CHOICE: A**

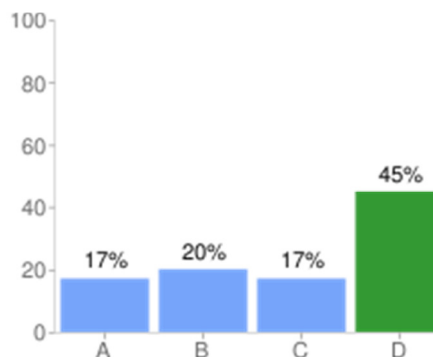
AMM019: Water molecules break down when heated (Griffiths et al., 1992).

ANSWER CHOICE: B

AMM086: The number of atoms or molecules of a substance increases when the temperature increases and decreases when the temperature decreases (Herrmann-Abell & DeBoer, 2008).

ANSWER CHOICE: C

AMM091: The mass of the atoms or molecules of a substance increases when the temperature decreases and decreases when the temperature increases (Herrmann-Abell & DeBoer, 2007, 2008).

Distribution of Responses**Percent of students responding correctly**

Overall	45%
Grades 6–8	38%
Grades 9–12	58%
Male	48%
Female	43%
Primary Language is English	47%
Primary Language is <i>not</i> English	32%

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American Association for the Advancement of Science. (2011). *AAAS project 2061 science assessment website*.
<http://assessment.aaas.org/pages/home>

APPENDIX D

THE STEBI-B SURVEY

Please indicate the degree to which you agree or disagree with each statement below by circling the appropriate letters to the right of each statement.

SA = STRONGLY AGREE
 A = AGREE
 UN = UNCERTAIN
 D = DISAGREE
 SD = STRONGLY DISAGREE

1. When a student does better than usual in science, it is often because the teacher exerted a little extra effort.	SA	A	UN	D	SD
2. I will continually find better ways to teach science.	SA	A	UN	D	SD
3. Even if I try very hard, I will not teach science as well as I will most subjects.	SA	A	UN	D	SD
4. When the science grades of students improve, it is often due to their teacher having found a more effective teaching approach.	SA	A	UN	D	SD
5. I know the steps necessary to teach science concepts effectively.	SA	A	UN	D	SD
6. I will not be very effective in monitoring science experiments.	SA	A	UN	D	SD
7. If students are underachieving in science, it is most likely due to ineffective science teaching.	SA	A	UN	D	SD
8. I will generally teach science ineffectively.	SA	A	UN	D	SD
9. The inadequacy of a student's science background can be overcome by good teaching.	SA	A	UN	D	SD
10. The low achievement of some students cannot generally be blamed on their teachers.	SA	A	UN	D	SD

11. When a low-achieving child progresses in science, it is usually due to extra attention given by the teacher.	SA	A	UN	D	SD
12. I understand science concepts well enough to be effective in teaching science.	SA	A	UN	D	SD
13. Increased effort in science teaching produces little change in some students' science achievement.	SA	A	UN	D	SD
14. The teacher is generally responsible for the achievement of students in science.	SA	A	UN	D	SD
15. Students' achievement in science is directly related to their teacher's effectiveness in science teaching.	SA	A	UN	D	SD
16. If parents comment that their child is showing more interest in science at school, it is probably due to the performance of the child's teacher.	SA	A	UN	D	SD
17. I will find it difficult to explain to students why science experiments work.	SA	A	UN	D	SD
18. I will typically be able to answer students' science questions.	SA	A	UN	D	SD
19. I wonder if I will have necessary skills to teach science.	SA	A	UN	D	SD
20. Given a choice, I will not invite the principal to evaluate my science teaching.	SA	A	UN	D	SD
21. When a student has difficulty understanding a science concept, I will usually be at a loss as to how to help the student understand it better.	SA	A	UN	D	SD

22. When teaching science, I will usually welcome student questions.	SA	A	UN	D	SD
23. I do not know what to do to turn students on to science.	SA	A	UN	D	SD

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APPENDIX E

THE COMPLETE LIST OF STUDENT QUESTIONS
ABOUT PHOTOSYNTHESIS COMPILED FROM
WORKING ON GROUP CONCEPT MAPS TO IDENTIFY
AREAS IN NEED OF ADDITIONAL INSTRUCTION

Getting materials

- Where does the extra oxygen released from photosynthesis come from?
- What is the role of stomata?
- How is CO₂ caught?
- What part of the leaf does the CO₂ come from?
- Does the soil play a part in the process of photosynthesis?
- If you water a plant with something other than water, what happens?

Chlorophyll and Light

- What is chlorophyll?
- Can a plant have a different source of light?
- What else does chlorophyll do?
- Why do the leaves make a green color?
- Can you check how much chlorophyll is in a leaf?
- Does the amount of chlorophyll affect the color of the leaf?
- What is the role of sunlight?
- How does sunlight become energy?
- Where does the energy come from?
- How does chlorophyll relate to energy and sunlight?

Making Sugar

- It is right that CO₂, energy and molecules combine to make sugar?
- How does CO₂ turn into carbs?
- Is the energy sugar?
- How do you get C₆H₁₂O₆?
- How does C₆H₁₂O₆ connect to the carbs exactly?
- Can “bad” sugar be created? If so, how does this affect the plant?

Products and Use

- Does the plant use oxygen?
- What is respiration?
- What does respiration have to do with photosynthesis?
- How does the plant use the energy it makes?
- Do plants grow because of the food they make? Like Humans?

Other Questions

- What causes leaves to change color?
- How long does the photosynthesis process take?
- Does photosynthesis occur at different times (seasons)?

APPENDIX F

THE COMPLETE LIST OF STUDENT QUESTIONS
GENERATED FROM A NON-GRADED QUIZ ON PLANT FOOD
AND PHOTOSYNTHESIS DURING THE THIRD WEEK OF
INSTRUCTION

#4 Calvin cycle (8 times)

Calvin cycle does in the plant cell?

What are the battery names?

Light independent area

Terms

AAP after the Calvin cycle

#5 Equation of photosynthesis

Formulas and equations for photosynthesis

Chemical equation for photosynthesis What's the chemical equation for photosynthesis?

Word and chemical equations of photosynthesis

The chemical formula of photosynthesis

The chemical formula for glucose

Glucose equation

The chemical equation for glucose

Chemical formula and equations

Word, chemical equation

Word/chemical equation

Examples of plant food

#6 What do plants do with food it makes?

What the plant does with the sugar once it's made it, it's been taken away but to where?

What does the plant do with the food? Also cellular respiration

What does the plant do with the food it makes?

What happens after the food is made – how the plant uses the food

What is food used for?

What is cellular respiration?

Cellular respiration connection

Cellular respiration

What is cellular respiration?

Cellular respiration

How does photosynthesis and respiration relate?

How do the items for Photosynthesis get to chloroplasts?

How photosynthesis gets to chloroplasts.

How do the items needed for photosynthesis get to the chloroplasts?

What was being changed by chlorophyll?

What is the chlorophyll charging exactly? ADP? APP?

What is chlorophyll?

What happens after water is broken apart in the chloroplasts?

How does the Oxygen get charged in the light reaction? (Unclear question for me)

What is the relationship between chlorophyll and chloroplasts? Is all of that found in the cell?

Chlorophyll – not sure if I have the right definition.

Plant parts

Why the substances make things?

How do capillaries transport and give away water?

Roots, what do they do?

I'm also uncertain of which things are split and powered up other than CO₂ and H₂O

How long does the photosynthesis process take?

APPENDIX G

A COMPILATION OF STUDENT GENERATED ITEMS
THAT NEEDED ADDITIONAL INSTRUCTION
ON PLATE TECTONICS

Students selected their own method of formative assessment by writing a summary, creating a concept map, or creating a group concept map.

Transform Boundaries

Explain more about transform boundaries

Transform boundaries-where

Transform boundaries

Transform – where and how?

Hess and Wegener's theories

Hess and Wegener

Wegener and Hess

Wegener and Hess

Convergent/volcanoes/subduction

Two types of convergent boundaries

Explain stars and square diagram

Subduction probe answers

Explain subduction diagram from probe

Subduction

What forms a trench?

Where does the plate go after subduction?

Is the plate gone forever?

What causes volcanoes?

Subduction and volcanoes

Subduction and volcanoes

Do only divergent plates cause volcanoes?

Divergent plates and volcanoes

Other questions

How do they know all this?

Will there be a day with no more earthquakes?

Layers of the earth

What separates earth's layers?

How is the core related to plate tectonics?

Consistency of the mantle

Mantle –solid or liquid

Lithosphere and asthenosphere

Asthenosphere. Where is this?

Convection current

How do we know 80% is mantle?

Continental drift evidence

Evidence of continental drift

Evidence of continental drift

Continental drift

Faults

Can faults divide a whole continent?

Can faults divide a continent like the rift valley?

Plate boundaries on a map

Plate boundaries on a map

What determines boundaries?

Plates only explain rocks/magma

Is the number of plates the same?

Can plates break? Disappear?

What makes the ring of fire?

APPENDIX H

INTERVIEW GUIDES

Interview Guide – Pre-study

1. How do you feel about formative assessment?

Why?

What does FA look like to you?

How might you use FA in your own teaching?

What is the purpose of FA?

Is it valuable to you as a student? As a teacher?

2. Assuming you want to understand formative assessment better, what do you think would help your understanding?

3. Before we address these topics in class, what do you know about plant food (and plate tectonics)?

What topics might be connected to plant food (and plate tectonics)?

What things about plant food (and plate tectonics) do you think are missing in your understanding?

Why should we know about plant food (and plate tectonics)?

How do plate tectonics explain our earth?

In science, what is meant by plant food?

5. What could a teacher do to help you understand a difficult science concept?

How do you intend to teach a challenging science concept in your classroom?

6. How do you feel about teaching science?

Are you excited? Scared? Confident?

How will you teach a science concept if you struggle to understand it yourself?

What could you do?

Extra time:

How can a methods course help you build science teaching confidence?

Suggestions?

What has worked for you?

Which science courses have you taken at college?

Have these courses help your understanding of science?

How have they helped your ability to teach science at the elementary level?

What could be done to help you be a better elementary science teacher?

Interview Guide – mid-study

Thanks for taking the time to be interviewed. I will try to keep this to no more than 30 minutes of your time. The questions all relate to your learning experience in Teaching Science and Social Studies. I am interested in you learning of plant energy, formative assessment, and how it applies to your future teaching.

Content:

Has your understanding of photosynthesis and plant food improved? How do you know?

On a scale of one to ten, how would you rate your understanding of plant food and photosynthesis before this class to now? Before _____ Now _____

On the last day of photosynthesis, were your questions answered?

If so, what was one question that was answered for you?

If not, what was one question that you still have?

Formative Assessment:

In our unit on plant food and energy, we used 3 specific formative assessment tools: assessment probes, concept maps, and a non-graded quiz (It would be helpful to have these items available to look at- the probes and the science notebook).

How did the assessment probes (apple tree, chlorophyll, plant food) help your understanding of plant food and energy?

How did the concept maps help your understanding of photosynthesis?

How did the non-graded quiz help your understanding of photosynthesis?

Which type do you think helped your understanding the most? Why?

How has your understanding of formative assessment changed through this learning experience?

Do you think the formative assessment tools used in this class helped Mr. Brower to teach the science topic more effectively?

Explain.

Do you think Mr. Brower's use of formative assessment helped him teach for your understanding?

Could you give an example?

Attitudes:

Has this learning experience influenced your attitude towards teaching science?

Positive? Negative? Confidence? Fears?

Future teaching:

So far, how has this learning experience changed your ability to teach elementary science?

So far, how has this experience changed your ability to understand challenging science content?

Right now, are you more likely to use formative assessment in your class than you would have before this experience? What strategies would you most likely use?

Interview Guide – post-study

1. How do you feel about formative assessment?

Why?

What does FA look like to you?

How might you use FA in your own teaching?

What is the purpose of FA?

Is it valuable to you as a student? Please explain?

2. What one thing has helped you understand formative assessment the most?

3. How has formative assessment helped you understand plant food and plate tectonics in this class?

4. What is plant food?

Define it, describe it, what's it used for, where does it come from?

5. What is a tectonic plate? What does it help explain?

6. How has doing formative assessment in this class influenced your teaching in the future?

Interview Guide- student teachers

Reflecting back on your course teaching science and social studies, what do you remember most that has influenced your student teaching experience?

What need for formative assessment have you seen in your teaching?

Have you seen your cooperating teacher using formative assessment?

If so, what has she/he done to use formative assessment?

Have you been able to use formative assessment in your student teaching experience?

How many times can you remember using formative assessment?

What are some examples of how you used formative assessment?

Has this been supported by your supervisor/cooperating teacher?

Do your students have misconceptions in science?

How do you know?

If so, what have you done about them?

Looking back at our education program, what influenced your attitudes towards using formative assessment in your own teaching?

APPENDIX I

SCIENCE NOTEBOOK ENTRIES

- What is science? How do you feel about teaching science?
- Plant observations from outside with an attached leaf
- Science skill: observations with mystery items inside plastic eggs
- Assessment definitions
- Science Skill: Classifying items as a group

- Chapter 1 reflection: Why Science?
- Density Lab: data charts
- Density Lab: conclusions
- Science skill: communication drawings with a partner
- Science skills: design four activities for students using 4 different science skills

- Share your own encounter with nature
- Motivation: Why do you want to learn science?
- Magic tube of science predictions
- Student examples of types of questions
- What is photosynthesis –student’s diagram

- Photosynthesis notes from class
- Concept map for plant food
- Vernier probe data from peer lesson
- Density Concept map
- Student personal science biography

- Personal science questions – what would you like to know?
- Chapter 6 reflection – Planning investigations
- Investigable questions
- Photosynthesis Quiz – with student questions
- Science activity day – five favorites explained

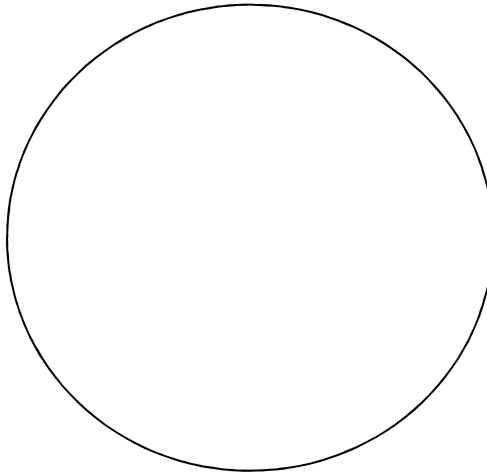
- Science and Children Article 1 reflection
- Science and Children Article 2 reflection
- Sharing science websites – pick your favorites
- Reflections on learning photosynthesis
- Data/thoughts from peer lessons on using science notebooks

- Plate tectonic notes from online resources
- Plate tectonics learning objectives
- Chapter 9 assessment reflections
- Goggles, nail, paperclip entry from peer lesson
- Final review of plate tectonics – summary or concept map with questions

APPENDIX J

PLATE TECTONICS PRETEST

1. What is the theory of plate tectonics?
2. Describe the earth's crust. What is it like?
3. Imagine the circle below is a cross-section of the earth. Draw and label any layers you think exist.



4. _____ crust is thicker, less dense, and older than the _____ crust.
5. _____ crust is thinner, more dense, and newer than the _____ crust.
6. The Lithosphere includes which two layers of the earth?

7. Which layer of the earth comes in contact with and moves the earth's plates?

8. The earth's _____ is the largest layer of the earth and is made up of hot dense rock that flows and moves the asthenosphere.
9. The earth's _____ is mainly made up of liquid iron and nickel because of extreme pressure and heat.
10. The earth's _____ is mainly made up of solid iron and nickel.

11. How do earth's plates move?

12. How do plates move at a convergent boundary? Draw or explain.

13. How do plates move at a transform boundary? Draw or explain.

14. How do plates move at a divergent boundary? Draw or explain.

15. Which type of boundary forms a rift? _____

16. Which type of boundary forms a trench? _____

17. In the box on the right, draw a convection current.



18. Where do volcanoes, earthquakes, and mountain ranges mainly occur?

19. _____ is the idea that the continents are moving away or towards one another.

20. What is Pangea? Who came up with the idea of Pangea?

21. What are two pieces of evidence for Pangea?

a. _____

b. _____