GAPS IN SCIENCE CONTENT KNOWLEDGE ENCOUNTERED DURING TEACHING PRACTICE: A STUDY OF EARLY-CAREER MIDDLE-SCHOOL SCIENCE TEACHERS

By

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ABSTRACT

GAPS IN SCIENCE CONTENT KNOWLEDGE ENCOUNTERED DURING TEACHING PRACTICE: A STUDY OF EARLY CAREER MIDDLE-SCHOOL SCIENCE TEACHERS

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Subject-specific content knowledge is crucial for effective science teaching, yet many teachers are entering the field not fully equipped with all the science content knowledge they need to effectively teach the subject. Learning from practice is one approach to bridging the gap between what practicing teachers know and what they need to know. This dissertation explores one aspect of learning from practice: when and how teachers encounter gaps in their science content knowledge during teaching practice and whether and how the teachers recognize those gaps. Classroom lessons of six early-career middle-school science teachers in three states were observed and video-taped to document apparent gaps in their science content knowledge. The observations were followed by interviews with each teacher to determine when the teachers encountered science content knowledge gaps, the nature of those gaps, and whether the teacher recognized the gaps. Additional analysis focused on how the observed gaps may have been influenced by teachers' undergraduate science coursework, expressed confidence in their knowledge of the subjects they were observed teaching, and level of daily preparation to teach. Practices that helped teachers recognize gaps in their knowledge (and consequently opened opportunities to learn from practice) were identified, as were common practices that seemed to hinder learning from practice.

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I dedicate this dissertation to Leah.
Thank you for your love, support, and patience during this journey.

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CHAPTER 1

INTRODUCTION

On January 5, 2010 the National Council for Accreditation of Teacher Education (NCATE) announced the organization of a blue ribbon panel to initiate a “mainstream move to more clinically based preparation of teachers.” One of the main foci of this panel was teachers’ “ongoing opportunities for learning” (2010, ¶ 1), which, among other things, can include opportunities for learning content knowledge beyond teacher preparation.

Solid subject matter knowledge (SMK) is crucial for effective teaching (Ball, 2000; Shulman, 1986), yet according to Shulman (1986), research and policy in education did not focus on teachers’ knowledge of the subject matter for much of the twentieth century because more emphasis was placed on studying pedagogy. Additionally, Shulman described and defined pedagogical content knowledge (PCK), or “subject matter knowledge for teaching” (p. 9), which merged both content and pedagogy and is also important for teachers to learn. In recent years, scholars in teacher education have recognized the importance of teacher content knowledge, which includes both SMK and PCK, for teaching. Yet teacher education programs still struggle to effectively provide this knowledge. According to Trachtman, Koenigsberg, and Levine (2008), “the professional preparation of teachers is not completed during the pre-service program, irrespective of the format through which it is provided (e.g., four-year undergraduate, M.A.T., five-year combined program)” (p. 5). Further, as Ball (2000) noted, “despite its centrality, usable content knowledge is not something teacher education, in the main, provides effectively” (p. 243).

Even so, teachers “are often treated as if they were ‘finished products’ when they graduate from teacher education programs” (Brickhouse & Bodner, 1992, p. 14). However, given the relatively limited amount of time that can be spent in teacher education programs, these programs cannot realistically provide comprehensive in-depth coverage of the subject matter (SMK) and the best subject-specific knowledge for teaching (PCK) for each subject area. When that is coupled with the increasing demands placed on new K-12 teachers, it is not surprising that many teachers are entering the field with varying degrees of content knowledge in the subjects they teach (Abd-El-Khalick & BouJaude, 1997; Akerson, 2005; Bennett, 1993; Smith & Neale, 1989). Incomplete science content knowledge can be especially challenging for elementary school teachers, who are expected to be able to teach the spectrum of subject matters at multiple grade levels. There is also evidence, however, that new middle and secondary science teachers are entering the field ill-equipped with regard to subject matter.

It is important to find ways to better understand the science content knowledge teachers have when they enter the field of teaching. It is equally important to understand where their knowledge is lacking and what kind of gaps early-career teachers encounter in their science content knowledge. One way teachers' knowledge, or lack thereof, can manifest itself is when teachers need to know something to teach the subject effectively but do not currently have that knowledge. Understanding these *content knowledge gaps* and how teachers may recognize or respond to them can be a useful tool for facilitating teacher learning from practice.

In light of these issues, the present study entailed identifying and analyzing gaps in early-career middle-school science teachers' science content knowledge, determining whether teachers recognized these gaps in their science content knowledge, and analyzing how they responded to these gaps. The content knowledge gaps data were obtained through classroom observations and follow-up interviews that focused on instances during these teachers' practice where there were observed potential gaps in their science content knowledge.

Inadequate Science Teacher Knowledge

Many studies have suggested that elementary-certified teachers lack basic science content knowledge. Smith and Neale (1989) reported that nine out of 10 elementary teachers in their study had limited science content knowledge and background, shared some of the same misconceptions as their students, and expressed feelings of inadequacy at the notion of teaching science. Akerson, Flick, and Lederman (2000) concluded that most elementary-certified teachers are more prepared to teach math and literacy than science. Bennett (1993) reported that preservice primary teachers in a teacher education program in England had limited science conceptions both before and after their teacher education course, indicating that their teacher education was not fully preparing them to teach science. Further, in a review of the literature, Akerson (2005) concluded that it is no surprise that elementary teachers' "conceptions of science content may be incomplete, and university coursework may not help to improve their science knowledge" (p. 245).

Studies have also shown that secondary science teachers in the United States and internationally are entering the field with inadequate science content knowledge. In their study including seven secondary biology teachers, Hoz, Tomer, and Tamir (1990) found that "the disciplinary and pedagogical knowledge of teachers of… biology is quite unsatisfactory" (p. 973). They also contended that "teachers are probably unaware of their missing or deficient knowledge and hence are prone to misteach their students" (p. 982). In another study of 16 first-year secondary science teachers, Roehrig and Luft (2004) found that the teachers had challenges teaching science as inquiry. Additionally, Lemberger, Hewson, and Park (1999), in case studies of three preservice secondary biology teachers, noted inadequacies in the teachers' conceptions of teaching science and their biology knowledge base. Other studies have also found evidence of inadequacies in secondary teachers' conceptions of the nature of science (Abd-El-Khalick & BouJaude, 1997).

In a review of literature on the challenges new science teachers face, Davis, Petish, and Smithey (2006) reviewed 112 studies of preservice and early-career elementary and secondary science teachers. Of particular relevance to the present study is their theme on "understanding the content and disciplines of science" including "substantive knowledge of science content" (p. 613). Although 59 of the reviewed studies contributed to the science content theme, only five focused on early-career teachers at either the secondary or elementary levels. Additionally, overall, only 13% of the 112 studies focused exclusively on early-career teachers. Discussing this disparity between research on preservice and early-career science teachers, Davis and her colleagues suggested that "early-career teachers may differ from preservice teachers in important ways, and certainly different questions can be asked of them" (p. 637).

Interestingly, few studies that have observed and reported gaps in science teachers' content knowledge were specifically looking for gaps in teachers' science content knowledge. In many cases, gaps in a teacher's knowledge were cited as indicators of why teachers may have been having difficulty mastering other important aspects of science teaching such as understanding the nature of science (NOS) in the context of teaching (Abd-El-Khalick & BouJaude, 1997; Da-Silva, Constantino, Ruiz, & Porlan, 2007; Schwartz & Lederman, 2002), teaching science as inquiry (Roehrig & Luft, 2004), and developing a professional identity (Volkman & Anderson, 1998).

Addressing Gaps in Science Content Knowledge

For the purposes of the present study I define gaps in science content knowledge using Sandkuhler and Bhattacharya's (2008) definition of a *cognitive problem*: "the gap between where we are now (initial state) and where we want to be (goal state, solution)" (p. 1). In other words, the teachers' level of science content knowledge at any given moment is the initial state, and what they need to know to effectively teach their science subject to their students is the goal state.

The National Science Education Standards (NSES) (National Research Council, 1996) provides a standard (or goal state) for science teacher knowledge. Regarding these science content knowledge standards, the Interstate New Teacher Assessment and Support Consortium (INTASC) (2002) has set a high bar for both teachers of science and science teachers:

> While all teachers of science (Grades K-12) have the depth and breadth of understanding described in NSES, science teachers (Grades 7-12) have even greater depth of understanding in at least one science discipline. All science teachers also have had the opportunity to participate in scientific inquiry, beyond what occurs in the typical laboratories of higher education. Such an experience of scientific inquiry is a prerequisite to assisting students as they come to understand science as inquiry. (p. 3)

According to Feiman-Nemser (2001), however, undergraduate education programs "provide limited opportunities to develop deep understanding… Thus it is not surprising that teachers lack conceptual and connected knowledge of the subjects they teach" (p. 1020). Consequently, this challenge has led to research and practices aimed at helping teachers bridge the gaps between what they know and what they need to know.

Professional development (see Lee et al., 2004; Putnam & Borko, 2000; Supovitz & Turner, 2000), educative curriculum (see Ball & Cohen, 1996; Collopy, 2003; Davis & Krajcik, 2005; Remillard, 2000), modeling (see Briscoe & Prayaga, 2004; Duckworth, 1986; Smith & Neale, 1989; Southerland & Gess-Newsome, 1999), and teacher induction (see Davis, Petish, &

Smithey, 2006; Feiman-Nemser, 2001; Roehrig & Luft, 2006) have all been suggested and successfully implemented to help close the gap between what teachers know and what they need to know. Yet, although some teachers have reported that they get the most improvement of their teaching from actual teaching (Smylie, 1989), relatively few studies have explored how teachers learn from their firsthand experiences teaching.

Learning from Teaching

The teaching process (including preparing to teach, interacting with students, and reflecting on teaching) can be a site for learning science content knowledge. However, Wilson and Berne (1999) reported that "extensive studies of teacher learning through practice have not yet been conducted" (p. 174). Although relatively few studies have focused on teachers learning from their practice, it has been well documented that if a person goes through the process of explaining something to someone else, they often learn it better themselves (Cloward, 1967; Palincsar & Brown, 1984). Some studies of teachers in practice have reported that teaching can increase the teachers' understanding of the subject matter (see Akerson, 2005; Akerson, Flick, & Lederman, 2000; Roehrig & Kruse, 2005; Sherin, 2002; Osborne, 1998). Studies have also shown that opportunities to teach a group of students early in a preservice teacher education program, similar to what NCATE (2010) proposes, have led to increased science content knowledge (see Bryan & Abell, 1999; Zembal-Saul, Blumenfeld, & Krajcik, 2000; Zembal-Saul, Krajcik, & Blumenfeld, 2002).

An Initial Study of Teachers' Learning from Practice

In an initial exploratory study (Kinghorn, 2008) I examined the ways 10 elementary certified teachers at different stages of their careers learned new science content knowledge from their teaching practice. I conducted one-on-one interviews with each teacher, focusing on how and what they learned as they taught science at the elementary level. The research questions for the study were:

1. What conditions of teaching can trigger elementary school teachers to learn new or enhanced science content knowledge?
2. How is this new science content knowledge gained?
3. What is the nature of this learning?

This research resulted in a list of potential types of events or situations in the teaching process (including preparing to teach, interacting with students, and reflecting on teaching) that can act as triggers for learning new science content knowledge. The interviews also provided information about the sources teachers sought out to find new information and the types of content knowledge (SMK and PCK) that teachers learned as a result of these learning triggers (see Table 1.1).

Table 1.1
Triggers, Sources, and Knowledge

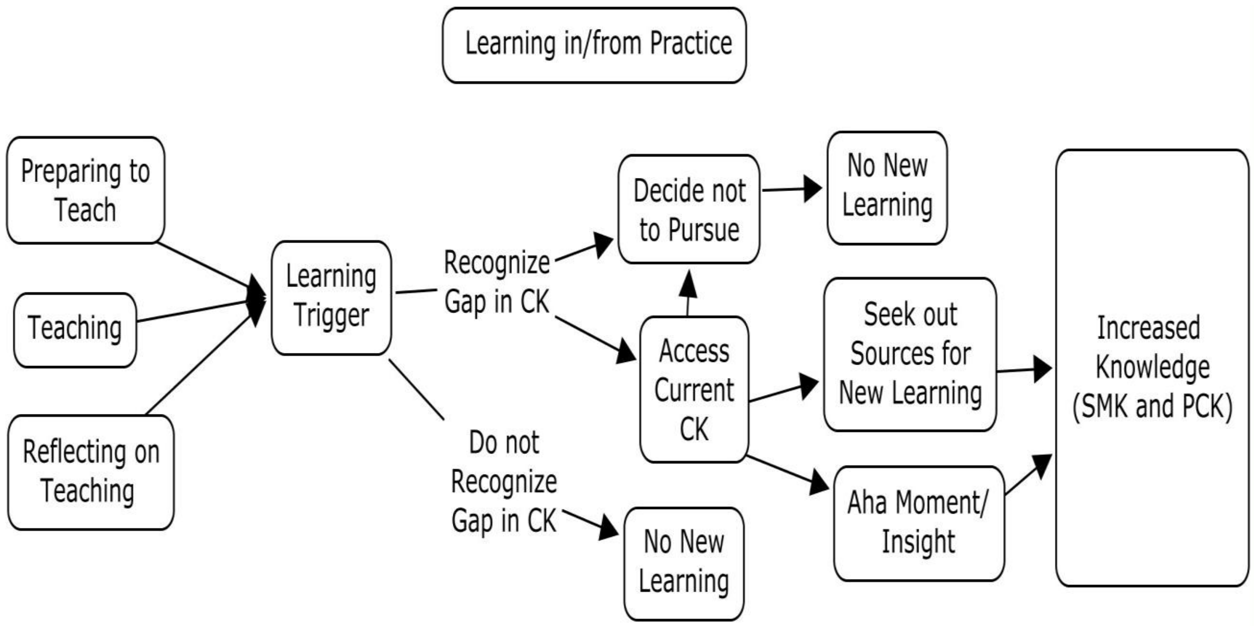
Triggers	Sources	Knowledge	
Anticipating Teaching New Material	Practice (In or Out of Class)	SMK-Syntatx, Rules & Procedures	PCK-Orientations
Recognizing Inadequate Curriculum	Others (in school or professional dev.)	SMK- Subject Organization	PCK- Knowledge of Students
Classroom Discourse (student questions, comments, etc.)	User-Friendly Resources (books/Internet)	SMK- Subject Facts, Concepts, Frameworks	PCK- Knowledge of Curriculum
Reflection on Practice	Insight (aha moments)		PCK- Instructional Strategies
Reflection in Practice			PCK Content Representations

Note: This table was produced from the available data from the study and is not meant to be interpreted as a comprehensive list of triggers, sources, and/or knowledge.

Based on these triggers, sources and knowledge types (which are not a comprehensive list), I created a framework for teachers' learning from practice (see Figure 1.1). In the process of

Figure 1.1

Model for Teacher Learning In and From Practice



preparing to teach, interacting with students in the classroom, or reflecting on teaching, the teachers had opportunities to realize that their current science content knowledge was lacking in some way. Each of these potential learning triggers acted as a possible impetus for the teacher to learn something new. Because all of the data came from the teachers' self-reports and any information I had about learning triggers came from the teachers, it was not possible to document instances when the teachers did not recognize the triggers or the gaps in their content knowledge. However, science teacher observations from other research (see Britton & Kinghorn, in progress; Putnam, Britton, & Otten, 2009) clearly showed instances when teachers failed to recognize probable gaps in their science content knowledge that were observed by the researchers (i.e., content errors made by the teacher, failure to accept a plausible student answer that was not what the teacher was 'looking for' (Kinghorn & Britton, in progress)).

When the 10 teachers in the initial exploratory study (Kinghorn, 2008) described triggers for learning, they did not always take the opportunity to learn new science content knowledge.

For example, one teacher reported that when she was unable initially to verify the correctness of student comments, she often said “that’s cool” and moved on. Other teachers described instances where a student comment or idea helped them to think differently about student learning (an aspect of PCK) or even learned a new concept themselves (such as the fact that a salamander is an amphibian). For many of the teachers, learning triggers included recognizing inadequacies in their curriculum, wanting to “get it right” for their students, or being assigned to teach something they had never learned before. There were also many ways student input could trigger new learning. In each instance when the teachers recognized gaps in their knowledge, they accessed their current science content knowledge, comparing the new information with previous experiences, as described by Harlen (1996). Sometimes the teachers experienced aha moments when the solution came fairly quickly just by thinking about it. Other times teachers had to decide whether to invest more time and energy to learning something new and what sources to turn to for this information to increase their knowledge.

Although the initial exploratory study provided useful information about the processes and particulars of how a group of elementary certified teachers learned from their teaching practice, it was limited by including only self-report interviews of the teachers. Further, although Figure 1 provides a useful preliminary framework for understanding learning science content knowledge from the teaching process, each aspect of the process requires additional research and analysis.

Purpose of the Study

This exploratory study builds upon the findings of the initial study through classroom observations and interviews of six early-career middle-school science teachers in three states. Where the initial study had a broader scope of preparing to teach, actual instruction and reflecting on teaching in addition to focusing on learning triggers, sources of knowledge, and types of knowledge learned, the present study had a narrower focus. Through classroom observations of teaching and follow-up interviews, the present study focuses on identifying classroom events and behaviors that potentially indicated gaps in the teachers' science content knowledge during instructional activities, and determining (a) whether these observed indicators identified actual gaps, and (b) whether the teachers recognized these gaps. Additionally, the study addresses teacher practices that seem to influence the numbers of gaps encountered during instructional activities and whether teachers recognize the gaps they encounter.

To learn from practice teachers must recognize gaps in their content knowledge and recognize when they are "faced with something new" (Harlen, 1996). Understanding what situations or attitudes toward learning can tend to trigger recognition of content knowledge gaps is an important aspect of this research. It is also important to understand the situations or attitudes that prevent teachers from recognizing gaps in their content knowledge, or from realizing that new information might inform and/or expand their knowledge base.

The study focuses on early-career middle-school science teachers because they are more likely than seasoned teachers to experience gaps in their content knowledge while teaching. According to the National Research Council (NRC) (1999) "experts have acquired extensive knowledge that affects what they notice and how they organize, represent, and interpret information in their environment…. [which] affects their abilities to remember, reason, and solve problems" (p. 19). Additionally the NRC concludes that "experts notice features and meaningful patterns of information that are not noticed by novices…. [and] have varying levels of flexibility in their approaches to new situations" (p. 19). However, although early-career middle-school teachers are generally clearly distinguished from their expert colleagues, middle-school science teachers can also have a broad array of science background knowledge preparation. For example, some middle-school teachers have elementary certifications, others may have secondary certifications, and other teachers may have emergency credentials with a background in science but no formal teacher education courses (see Britton & Kinghorn, in progress).

Although nearly all early-career middle-school teachers would be considered novices by most definitions, the nature and depth of their training and science background knowledge is likely different from their colleagues. Some teachers with secondary certification may be further along the spectrum and be able to notice more new experiences and better recognize instances that may identify gaps in their content knowledge. Other teachers with a more broad-based elementary education certification may be at lower points on that spectrum. And some teachers may be proficient in one subject area but are teaching in another, and that may have some effect on whether they recognize gaps and how they learn from practice (Kinghorn & Britton, in progress). The study was not designed to systematically study differences in background knowledge and how those differences affect teacher learning. However, the issue of how background knowledge can affect the recognition of content knowledge gaps and learning is important, so it is addressed in this research at a preliminary level by diversifying the participants based on their science preparation backgrounds.

Research Questions

The main research question guiding this research is: When do middle-school science teachers recognize gaps in their content knowledge? Four subquestions help address the main question:

1. What classroom events serve as potential indicators of gaps in teachers' knowledge?
2. Do certain classroom events trigger teachers’ recognition of gaps?

3. How does the depth and nature of teachers' knowledge affect their content knowledge gaps?
4. What teaching practices can help teachers better recognize and address gaps in their content knowledge?

Overview of Dissertation

Chapter 2 lays out the conceptual framework of science teacher knowledge and reviews relevant literature related to teacher learning from practice. Chapter 3 outlines the methods employed in selecting participants and the gathering and analysis of the data for the dissertation. The results are divided into three chapters, one chapter for each of the subresearch questions noted above. Chapter 4 focuses on the gaps observed in the teachers' science content knowledge and whether the teachers recognized these gaps. Chapter 5 addresses some of the ways that the teachers' background knowledge, relative levels of confidence in their knowledge, and daily preparation to teach related to these gaps. Chapter 6 focuses on teaching practices that the teachers engaged in that seemed to either facilitate or hinder learning from practice. Finally, Chapter 7 is a discussion and overview of the dissertation.

CHAPTER 2

LITERATURE REVIEW

This dissertation is grounded in previous research about teacher knowledge and frameworks of teacher knowledge. This chapter describes the conceptual framework of science teacher knowledge based on current models of teacher knowledge, with specific emphasis on *subject matter knowledge* (SMK) and *pedagogical content knowledge* (PCK). This is followed by a review of literature on teachers learning from their own teaching practice. This review addresses research that focuses on classroom discourse, teacher reflection, learning from curriculum materials, and preservice learning from teaching.

Conceptual Framework

Recent models of science teacher knowledge include the constructs and interactions of SMK, *pedagogical knowledge* (PK), PCK, and *knowledge of context* (KofC) (Abell, 2007; Grossman, 1990; Magnusson, Krajcik, & Borko, 1999), as shown in Figure 2.1. Although PK and KofC are important aspects of a teacher's knowledge, this study is framed within SMK and PCK, the types of knowledge that relate specifically to the science subject being taught. Consequently, I will not explain PK or KofC beyond the information in Figure 2.1.

Subject Matter Knowledge (SMK)

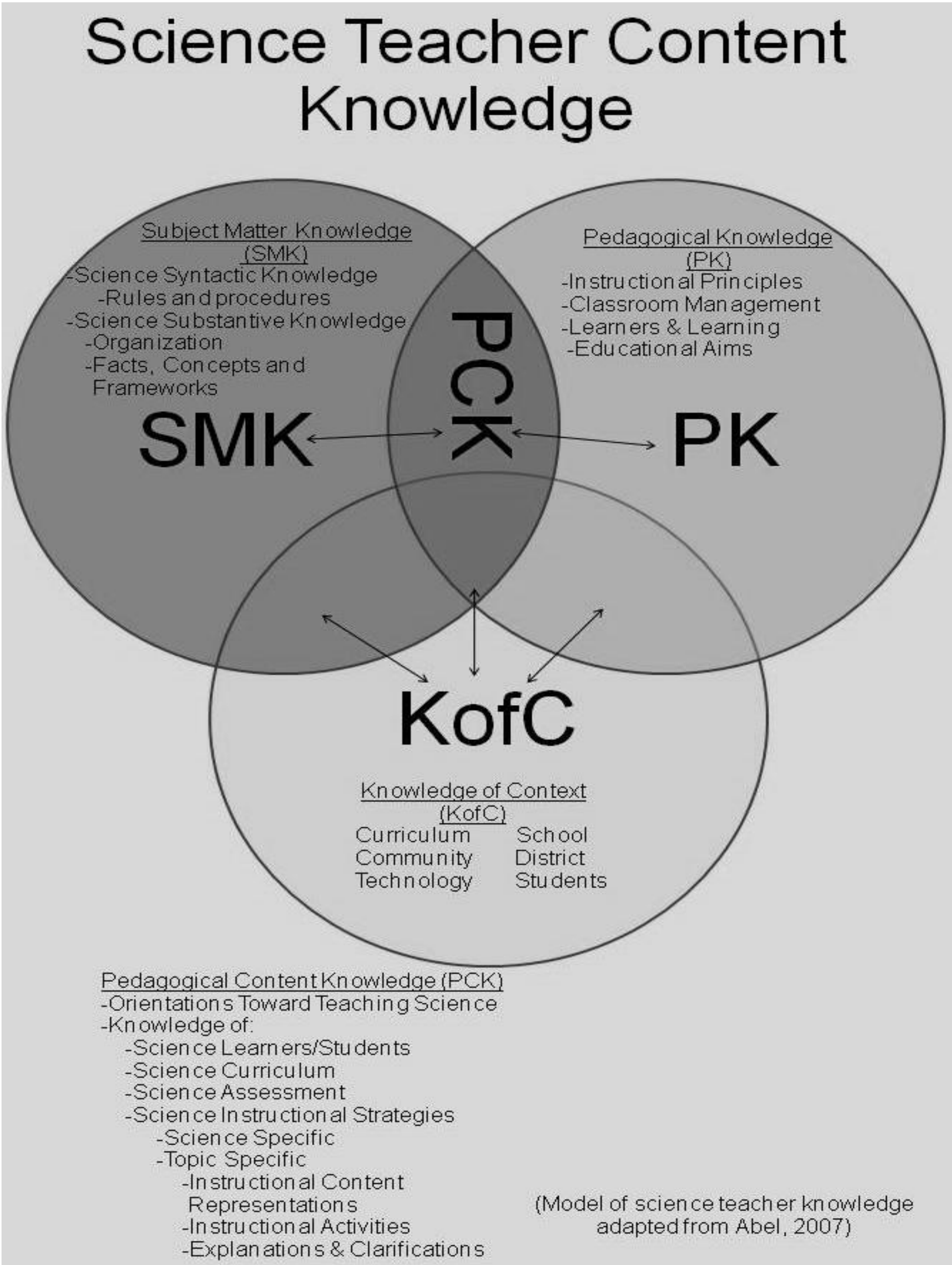
In Shulman's (1986) model of teacher knowledge, SMK includes an understanding of the knowledge, facts, and structure of a subject area. More recently, models of science teacher knowledge have expanded the definition of SMK to include science syntactic knowledge and science substantive knowledge (Abell, 2007; Grossman, 1990; Magnusson, Krajcik, & Borko, 1999). Syntactic knowledge includes the rules and procedures of engaging in science inquiry. Substantive knowledge includes how a topic is organized (Abell, 2007). Substantive knowledge also includes information that the scientific community has agreed upon. This information can come in the form of taxonomies, theories, laws, nomenclatures, facts, concepts, and frameworks. SMK is the substance of a topic and is necessary for teachers to know in order to teach the topic well. Although each construct of science teacher knowledge is important and influences the others, SMK is arguably the most important aspect of the model; without it there would be no science teaching. Additionally, all the other aspects of teacher knowledge are generally developed and defined in relation to the subject matter. The National Science Education Standards (NSES) state: “Science subject matter focuses on the science facts, concepts, principles, theories, and models that are important for all students to know, understand, and use” (National Research Council (NRC), 1996, p. 106).

Teachers in my preliminary study (Kinghorn, 2008) talked about learning both syntactic and substantive SMK from their teaching practice. Regarding science rules and procedures, one teacher noted the benefit of learning how to go through the process of doing science experiments. Another teacher said she had realized that her students needed to be able to experiment and make mistakes as a process of inquiry or discovery. Eight of 10 teachers in the study shared many instances of learning substantive SMK, from learning that salamanders are amphibians to learning about constellations to understanding why we have seasons.

Pedagogical Content Knowledge (PCK)

Shulman (1986) defined PCK as “subject matter knowledge for *teaching*... the particular form of content knowledge that embodies the aspects of content most germane to its teachability” (p. 9). As Zembal-Saul, Krajcik, and Blumenfeld (2002) put it, “PCK is a teachers’ unique knowledge of how to create learning opportunities that make particular content more comprehensible to others” (p. 444). More recently, Abell (2007) defined PCK as

Figure 2.1



(Model of science teacher knowledge adapted from Abel, 2007) the knowledge teachers develop to help students learn. She also pointed out that "teachers build PCK as they teach specific topics in their subject area" (p. 89). In Abell's model of science teacher knowledge, PCK includes orientations toward teaching science, knowledge of science learners, knowledge of science curriculum, knowledge of assessment, knowledge of science instructional strategies, and content representations. This knowledge is topic-specific and often specific to the backgrounds and needs of particular students.

Orientations. According to Abell (2007), "Anderson and Smith (1987) introduced the term 'orientation' as a way to categorize disparate approaches to science teaching (activity-driven, didactic, discovery, and conceptual change)" (p. 106). Orientations toward teaching science include the ways the teacher approaches teaching science, but Abell called it a "messy construct" and pointed out stark differences between how it is researched and framed. Therefore, because knowledge of orientations tends to be a more subjective choice for the teacher and is accompanied by debate among researchers and practitioners about which orientations are best, this was not an area of focus in the study.

Knowledge of students. One aspect of PCK is knowledge of students. This can include understanding how students may think at their age or grade level or what kinds of background knowledge or experiences their students may already have. More specifically, knowledge of students can include understanding what common conceptions, misconceptions, or areas of difficulty that students may have. For example, many students hold the misconception that the seasons are caused because the distance between the earth and the sun changes (Schneps, 1989). Understanding students' thinking goes beyond knowing the subject matter concept that the tilt of the earth's axis and consequent direction and duration of the sun's rays are what cause the seasons. Teachers also need to know the incorrect conceptions about the seasons that many of their students may hold.

Through their teaching experiences, teachers can begin to understand their students and how the science content they are teaching specifically relates to their students (Kinghorn, 2008). Knowledge of students is essential for teachers to be able to *psychologize* the subject matter, or translate it “into the immediate and individual experiencing within which it has its origin and significance” (Dewey, 1902, p. 351). In other words, knowledge of students can allow teachers to tailor their lessons so that the content will be presented in developmentally and experientially appropriate ways for their students.

In the preliminary study (Kinghorn, 2008), the teachers shared many instances where they learned more about their students’ thinking. For example, one teacher shared how her lessons often changed because of her students. She started using science talks with her kindergarten students to both understand different ways her students thought about certain concepts and to understand their misconceptions.

Knowledge of curriculum. Another way teachers develop their PCK is through deepening their understanding of the curriculum materials. In Shulman's (1986) model of teacher knowledge, curricular knowledge was a distinct construct. Shulman defined curricular knowledge as an understanding of the programs in place to teach a particular subject at different levels. More recent models of science teacher knowledge include curricular knowledge as part of PCK and part of KofC (see Abell, 2007; Grossman, 1990; Magnusson, Krajcik, & Borko, 1999). Although knowledge of curriculum as an aspect of KofC includes general knowledge about the curriculum available and how the school expects it to be implemented, knowledge of curriculum as an aspect of PCK goes much more in depth. According to Magnusson, Krajcik, and Borko

(1999), knowledge of curriculum includes understanding local, state, and national science standards as well as specific materials. Curricular knowledge includes knowing what materials are available and necessary for particular lessons or activities, knowing exactly how labs or inquiry activities are supposed to work, including knowing how to set them up properly and understanding the content of and functions of all the materials and tools for the labs, demonstrations and/or lessons. Additionally, teachers must know the correct answers on worksheets, bookwork, or other assignments. This type of knowledge also includes understanding the desired (and possibly undesired) outcomes of the lessons, labs or activities. Knowing what might go wrong and being able to troubleshoot is often as important as knowing how things are supposed to go.

In the preliminary study (Kinghorn, 2008) nine of 10 teachers shared experiences in which they developed a greater understanding of the curriculum. One teacher said that the outside sources he turned to for support helped him develop a sense of the curriculum and what aspects of it were most important for his students. Another teacher shared that during her first year of teaching she did not even have her own copy of the standards and as she was "winging it" through the lessons and attended professional development seminars her curricular knowledge increased.

Knowledge of assessment. Knowledge of assessment includes understanding how to assess students' knowledge of science concepts specifically, and understanding science-specific assessment measures in general. It also includes knowing what to assess.

Instructional strategies. PCK also includes specific strategies for presenting or facilitating the learning of science in general or in specific science topics. It encompasses methods for teaching science. This can generally refer to the subject-specific use of analogies, demonstrations or labs. It also includes or topic-specific representations of science content (such as analogies, models, and examples), demonstrations of specific science content and classroom activities (such as labs, cases, demonstrations, experiments, and investigations) related to specific science content. An especially important aspect of instructional strategies is learning different appropriate ways to represent the science content.

One teacher in the preliminary study stated he came to realize that it was one thing to know the content and something completely different to understand and teach it at an age-appropriate level. Another teacher shared how she learned the importance of explaining concepts simply for her students even if it meant finding a different model. She also came to realize that if she could not appropriately represent the subject matter to her students she would not be able to help facilitate their learning.

Teachers Learning from Teaching

As noted earlier, a person who goes through the process of explaining something to someone else, often learns it better themselves (Cloward, 1967; Palincsar & Brown, 1984). In a case study of an early-career middle-school science teacher, Brickhouse and Bodner (1992) stated that:

> teachers construct knowledge about science, their students, and the science classroom that fits their experiences and meets their goals for themselves and their students. Some of this learning takes place in teacher education courses, but most of it occurs in the schools in which they teach. (p. 13)

Additionally, according to Osborne (1998), "through teaching the teacher becomes the learner" (p. 428), and the teaching process can be a "vehicle for teachers to define their own knowledge and recognize what they do and do not know" (p. 436). She stated, "as a teacher, I am…

continuously confronted with the inadequacy of my knowledge" (p. 427). Osborne concluded that teaching forces the teacher to "articulate and act upon… knowledge in [new contexts]… [and] knowledge is altered… through the act of articulation and the self awareness this entails" (p. 428). Dewey (1902) compared the disciplines of science to a map that is "a summary, an arranged and orderly view of previous experiences, [and] serves as a guide to future experiences..." (p. 351). Yet he also explained that, although the map can be used to teach and guide, it "is not a substitute for a personal experience... [and] does not take the place of an actual journey" (pp. 350). Learning in the preservice classroom could be thought of as reading a map and learning in the context of actual teaching as taking the journey.

Specific to teachers' learning, Smylie (1989) reported that teachers felt they got the most improvement in teaching from direct classroom experience. Additionally, studies have reported that classroom discourse with students (Akerson, 2005; Akerson, Flick, & Lederman, 2000; Jones, Carter, & Rua, 1999; Seymour & Lehrer, 2006), reflection on or in teaching practice (Abell, Bryan, & Anderson, 1998; Davis, 2006; Osborne, 1998), and trying to conform to reform-based curriculum materials (Roehrig & Kruse, 2005; Sherin, 2002) can lead teachers to increase their understanding of the subject matter and their PCK. Additionally, some preservice teachers have shown increased content representations (an aspect of PCK) from participating in authentic scaffolded teaching experiences early in their preservice education (Zembal-Saul et al., 2000, 2002).

Classroom Discourse

In a study of how students' conceptions of science influenced preservice teachers' professional growth, Jones, Carter and Rua (1999) concluded that students' science knowledge served as discrepant events that evoked teachers' dissatisfaction with their own content knowledge and motivated them to reconsider their pedagogical practices. Students' concepts also served as change agents, resulting in changes in teachers' views of their roles and instructional behaviors. (p. 545)

Taking these ideas further, Akerson (2005) explored classroom triggers that influenced teachers to compensate for their incomplete science knowledge. She and her colleagues (see also Akerson, Flick, & Lederman, 2000) observed two Grade 2 classrooms as teachers taught an astronomy unit. By analyzing the classroom discourse, Akerson concluded that student questions, comments, ideas, and research were all triggers that influenced the experienced teachers to compensate for their inadequate SMK by seeking out more knowledge of the subject. Additionally the experienced teachers developed their own PCK as they took time to listen to and understand student ideas (knowledge of learners) and come up with content representations that were developmentally appropriate for their students.

More recently, in a study of the conceptions of a secondary biology teacher, Da-Silva, Constantino, Ruiz, and Porlan (2007) concluded that "the catalyst of the change in her initial conceptions of teaching and learning was her becoming aware of the students' alternative ideas" (p. 462).

Teacher Reflection

In addition to learning from interactions with students, teachers also learn as they reflect on their teaching. According to Abell, Bryan, and Anderson (1998), "the ultimate intent of reflection in teacher education is for teachers to gain a deeper understanding of their practice in order to improve it" (p. 492). Reflective practices in modern education were promoted in teacher education as early as John Dewey (1933). There seems, however, to be a consensus among educational researchers that the reflective practices seen today stem from Schon's (1983, 1987) conceptualization of reflection (see Abell, Bryan, & Anderson, 1998; Davis, 2006; Kagan 1990).

According to Davis (2006), Schon (1983) characterized reflection in two ways: *reflection-on-action* and *reflection-in-action*. She said that “reflection-on-action includes planning and looking back on one's practice; reflection-in-action... guides teachers' in-the-moment decision-making, and depends on their interactions with learners” (p. 282). Teaching self-reflection problem-solving practices to novice teachers is one way researchers have tried to bridge the content knowledge gap for new teachers of science (Abell, Bryan, & Anderson, 1998; Kagan, 1990). According to Abell, Bryan, and Anderson (1998), reflective teaching experiences—including reflecting on others' teaching, their own teaching, theories in educational research, and their own learning of science—can be a useful preservice tool to influence teachers' beliefs about teacher practice more effectively through their preservice teaching experiences.

Learning from Curriculum Materials

Another challenge science teachers can face is inadequacies in their curriculum materials (Kesidou, & Roseman, 2002). Textbooks and curriculum materials are often out of date and not in keeping with reform efforts. Teachers have often struggled with curriculum and have even experienced different levels of hostility towards texts (Ball & Cohen, 1996). In the preliminary study (Kinghorn, 2008), I found that elementary teachers learned both from studying good curriculum materials and from compensating for inadequate curriculum materials. Duckworth (1986) suggested that much of the curricula designed for children can be just as effective for teaching adults the same concepts. Although she was referring to professional development, the presence of and research on educative curricular materials (see Ball & Cohen, 1996; Davis & Krajcik, 2005) suggests that the curriculum can be a site for effective individual learning as well.

Additionally, studies have shown that reform-based curriculum can be a site for teacher learning. For example, Sherin (2002) found that teachers learned content knowledge as a result of mathematics reform implementations. She argued that mathematics reform requires that “existing content knowledge is modified during instruction... [and] new content knowledge is developed during instruction” (p. 120).

Preservice Learning from Teaching

It is clear that teachers are learning from their own practice in the field. Fortunately, the importance of practical experience for learning to teach science has also been emphasized in some teacher education programs. For example, Zembal-Saul and her colleagues (2002, 2000) reported that three preservice elementary teachers who had many supervised opportunities to teach early in their preservice education demonstrated a greater understanding of science content and better teaching practices in their student teaching year. They showed that teaching experiences during the junior year of college in an experimental new teacher education program helped prospective teachers to develop better SMK, PK, and PCK, which were demonstrated in their student teaching experience (last semester of senior year). This better knowledge was measured mainly in the form of better representations of the content.

Summary

This research builds upon previous research on science teacher knowledge and learning from teaching practice. As noted earlier, many of the cited studies addressed learning from teaching practice as a side note to other focus issues of the research. The current study focuses specifically on learning from teaching practice, and more specifically on one aspect of that process: when and how teachers encounter the gaps in their knowledge during teaching practice and whether they recognize those gaps.

CHAPTER 3

METHOD

The purpose of this research was to identify science content knowledge gaps middle school science teachers encountered during their teaching practice and determine when the teachers recognized those gaps in their content knowledge. Specifically, this qualitative multiple case study design research was conducted to determine what types of classroom events can indicate gaps in teachers' science content knowledge, and whether certain classroom events trigger teachers' recognition of their content knowledge gaps. It also focused on how the depth and nature of teachers' knowledge affects their content knowledge gaps and what teaching practices can help teachers better recognize and address gaps in their content knowledge. To address these questions, I observed and interviewed early-career middle-school science teachers. During the observations I paid particular attention to instances when teachers were potentially encountering gaps in their science content knowledge. Following each video-recorded observation I conducted a preliminary analysis of the videos and my field notes and identified the potential gaps which I then addressed in a follow-up interview for each observation. This use of observations with follow-up interviews was similar to other qualitative case studies about learning from practice (see Akerson, 2005; Akerson, Flick, & Lederman, 2000; Briscoe & Prayaga, 2004; Sherin, 2002; Zembal-Saul, Blumenfeld, & Krajcik, 2000).

Participants

The target population for this study was early-career middle-school science teachers in the United States. Middle-school science teachers were ideal candidates for this study because they generally teach science on a daily basis and can have varied preservice preparation, which means there is likely to be a broad spectrum of science knowledge background among the population. Additionally, early-career teachers may be more likely than seasoned teachers to have gaps in their science content knowledge, increasing the odds of observing gaps in a teacher's science content knowledge during randomly scheduled observations.

Six female early-career middle-school science teachers from six different schools participated in the study (see Table 3.1). Three of the teachers came from the same urban school district in Alabama, two from suburban schools in Iowa, and one from a rural school in Kentucky. The sample is a convenience sample of the population of early-career middle-school science teachers. In each location I knew individuals who were able to introduce me to teachers who fit the criteria for this study. I emailed a number of teachers in each location and received responses from the six teachers included in the study. Each teacher was instructed to secure permission from her principal for the study to be conducted before data collection began.

Data Collection

The data for this research came from classroom observations and follow-up interviews. It was important to conduct both observations and interviews because teacher content knowledge is often embedded in practice and not necessarily recognized or easily articulated by teachers (McIntyre & Hagger, 1993). Additionally, Carter (1990) contended that tying knowledge to situations is essential for understanding teacher knowledge in the context of teaching. Research also suggests that carefully crafted interviews, which allow teachers to openly share their thoughts, feelings, and experiences, can be a tool to study the development of content knowledge in the context of teaching. According to Munby, Russell, and Martin (2001), teacher knowledge is "heavily dependent on the unique context of a particular classroom, and teachers often express and exchange their knowledge… [as] anecdotes and stories" (p. 877). The combination of observations and follow-up interviews allowed me, as a researcher, to observe

Table 3.1
Participant Information

Teacher	State	Grade Level	Subject Being Taught	Year Teach-ing	Relevant Degrees	Credential	Took Undergrad Courses In:*
Ms. Lane	Alabama	7	Life Science	3	BS Biology	Alternative Secondary Certification	Biology, Chemistry, Physics
Ms. Ardis	Alabama	8	Physical Science	1	BS Biology Chemistry Minor	Emergency Secondary Credential (taking alternative certification courses)	Biology, Chemistry, Physics
Ms. Kidd	Iowa	7	General Science	2	BS Biology BA Secondary Education	5-12 Physics, General Science, Biology, & Chemistry Middle-school Endorsement	Biology, Chemistry, Physics
Ms. Keller	Iowa	8	General Science	2	BS Biology BA Middle Level Science Education	5-12 Physics, General Science, Biology, & Earth Science	Biology, Chemistry, Physics, Geology
Ms. Beam	Alabama	8	Physical Science	3	BS Health Science	Emergency Secondary Credential (taking alternative certification courses)	Biology, Chemistry
Ms. Mepps	Kentucky	7	General Science	2	BS 5-9 Grade Middle-school Math & Science	5-9 Grade Middle-school Math & Science	Biology, Chemistry, Physics, Geology

*Teacher completed at least one course in each general field of science listed.

and study gaps in teachers' science content knowledge in the context of classroom experiences as well as through teachers' thoughts and feelings about those experiences. The observations helped me see evidence of potential gaps in the teachers' science content knowledge, and the follow-up interviews allowed me to determine whether they were actual gaps and whether the teachers recognized the gaps.

Observations

I traveled to each of the three states twice, observing each teacher once per trip. I conducted the two observations for each teacher on different days of the week and, when possible, during different units of instruction (see Table 3.2). The first observation of each teacher took place in February, 2010, the second in March, 2010. I asked the teachers to let me observe on instructional days, not testing or review days. Because I did not want the teachers to know that I was looking for potential gaps in their knowledge, I did not ask them to prepare for the visits beyond securing permission from administrators and allotting time after school for follow-up interviews.

During each visit I observed and video-recorded each teacher teaching her first class of the day. This included taking detailed notes including the times of events in the classroom germane to the research questions. In accordance with IRB requirements, the video camera was focused on the teacher, not the students; only the teacher is visible in the recordings but audio from the entire class is captured. After observing the first class I left the classroom to conduct preliminary analysis of the observation in preparation for the follow-up interview later that day. I then returned to the teacher's classroom and observed her teaching the last class of the day. These classes were not video-recorded, but I took detailed notes, paying particular attention to any adjustments in instruction that differed from the first class I observed.

Table 3.2
Topics Covered During Teacher Observations

Teacher	Observation 1	Observation 2
Ms. Lane	Taught students about the base pairs in DNA and RNA	Taught students about the respiratory and circulatory systems of the human body
Ms. Ardis	Taught students about measuring acids and bases using the pH scale	Groups of students engaged in kit-based inquiry activities about simple machines
Ms. Kidd	Students made models of the earth out of different colored clay	Taught students about earthquakes & students began constructing model structures to later test in simulated earthquake conditions
Ms. Keller	Showed students a video about different forms of energy and discussed the information with her students	Taught students about atomic structure, including protons, neutrons, and electrons.
Ms. Beam	Students engaged in a kit-based inquiry activity constructing batteries using copper and zinc metals in a copper sulfate solution	Students engaged in a kit-based inquiry activity where they tested the life of batteries for a range of times spent charging the batteries
Ms. Mepps	Taught students about the differences between and make-up of mixtures, compounds, and solutions using worksheets	Taught students about the layers of the earth using a cutout activity

The main sites for identifying potential gaps in the teachers' science content knowledge were the observations of each teacher's teaching practice. The observation protocol (see Appendix A) focused on identifying classroom events that revealed potential gaps in the teachers' science content knowledge. This involved (a) looking for instances where the teacher appeared to encounter something new; (b) looking for examples of potential learning triggers; and (c) paying attention to the actions and behaviors in the classroom that could indicate potential gaps in the teachers' knowledge.

During each observation I paid particular attention to *potential learning triggers*, events or situations with the potential to illuminate or identify gaps in a teacher's content knowledge and potentially trigger her learning of new content knowledge. As noted in Chapter 1, the potential learning triggers I attended to came from my preliminary study of elementary school teachers learning from practice (Kinghorn, 2008). The potential learning triggers related to classroom instruction include student questions, student ideas or comments, student responses, teacher content errors, and unexpected outcomes of lessons (see Appendix A for complete list). Although these types of classroom events can potentially result in teachers encountering new information or gaps in their content knowledge, it is just as likely that these events will not challenge a teacher's knowledge (e.g., a teacher provides a conceptually appropriate response to a student question).

Consequently, I attended closely to how the teacher or students responded or reacted to the potential learning triggers I observed. In some cases the events were followed by observable actions or behaviors (from the teacher or students) or events suggesting possible gaps in the teacher's content knowledge. Examples of these *potential gap indicators* include: (a) the teacher did not respond to a question or comment; (b) the teacher stated she did not know something; (c) the teacher looked up information in class; (d) the teacher dismissed a potentially correct response from a student; (e) the teacher altered or rearranged the planned lesson to accommodate a student question or comment; (f) the teacher noticeably paused (presumably to think) during instruction; (g) students seemed noticeably confused by what the teacher was saying; or (h) the teacher made noticeable changes to the original lesson plan (see Appendix A for complete list). These potential gap indicators were often associated with observable potential triggering events such as student input. However, I also attended to potential gap indicators that were not preceded by easily observable events. This was important because the only observable evidence of a gap in a teacher's knowledge is the teachers' subsequent reactions or behaviors. Additionally, in some cases it was only apparent that there had been a gap in the teacher's knowledge because I saw evidence that the teacher had bridged that gap. For example, teachers explained a concept to their students in different ways and later shared that they had come up with the new explanation sometime during the course of teaching that day.

It is important to note that, although I attended to potential learning triggers throughout the lessons, I noted them only when they served as potential gap indicators (e.g., a teacher content error) or were followed by actions or behaviors that would be considered potential gap indicators. Only when a potential learning trigger was part of a sequence of events that indicated a potential gap in a teacher's science content knowledge was it relevant for this research.

The overall goal during the observations was to note all of the events in the classroom during which it seemed probable that teachers had encountered possible gaps in their knowledge. I used the follow-up interviews to determine whether these noted events actually indicated knowledge gaps and whether the teachers recognized these gaps. When I observed potential gap indicators, I briefly detailed the event in my field notes and noted the time of the event so it could easily be retrieved on the digital video recording for further review, initial data analysis, and possible inclusion in the follow-up interview.

Immediately after each video-recorded class of the day, I asked the teacher if she had "learned something new, encountered something new, or realized [she] did not know something" during class. I also asked if there were any parts of the lesson she would like to review in the follow-up interview. Through these questions I hoped to capture events in a classroom when teachers encountered gaps in their science content knowledge that I may not have observed or recognized. The questions also allowed me—like Akerson, Flick, and Lederman (2000)—to encourage teacher input in what was included in the interviews.

Initial Observation Analysis

Immediately after each observation I conducted a preliminary analysis of the video observations and my field notes to prepare for the follow-up interview with the teacher. During this initial analysis I viewed the entire video recording of the observed class. While watching the video I noted the time stamps of the events (based on observed potential gap indicators) I had noted previously in my field notes and looked for other potential gap indicators I may have overlooked during my initial observation. The potential gap indicators I noted served as stopping points to recall in the in the follow-up interviews because they provided observable evidence of probable gaps in the teachers' science content knowledge. However, without knowing what the teacher was thinking during these events it was not possible to confirm the potential gaps in their content knowledge.

During this initial analysis I augmented my field notes with additional information about the classroom events including transcribing some brief interchanges between the teacher and students to use in the interviews. Then, using my field notes and the input from the questions I asked the teacher immediately after the observation, I ranked each of the noted events on (a) their likelihood of indicating actual knowledge gaps; and (b) the complexity of the situations surrounding the classroom events. The first ranking helped me determine which of the events were most important to address in the follow-up interviews, recognizing that there might not be time to address all the events. Ranking the complexity of the situations helped me determine which events to view with the teacher during the follow-up interview and which to discuss without viewing video clips. In deciding which video clips to use in the interview, I chose events that were more complex or for which I risked inserting my personal bias in describing the event. For simpler events, such as a straightforward student question followed by a straightforward response from the teacher, I read the question and response back to the teacher rather than showing the video clip. Depending on the number of events I noted and the lengths of the video clips of these events, I selected up to six video clips of the more complex events that seemed most likely to actually indicated gaps to view with the teacher during the follow-up interviews. In some cases these video clips were lengthy and included multiple events, and in other cases I showed multiple short video clips of different events. I planned to verbally discuss the remainder of the events I noted with the teacher as time permitted.

Interviews

Within 24 hours of each observation I conducted a follow-up interview with the teacher (see Appendix B). These interviews began with preliminary questions about the teachers' background, as well as their feelings about and experiences with teaching science. Each interview then included general questions about the lessons the teacher taught during the observation, including her preparation for teaching and reflections on her teaching. Finally, each interview addressed the specific potential gaps I noted in my observations. Throughout the interviews I also looked for additional potential gap indicators based on teachers' behaviors and responses during the interview. These gap indicators occurred in two ways during the interview: (a) when teachers made a content error such as explaining a scientific concept incorrectly during the course of the interview; and (b) when teachers talked about events that had happened previous to the observed lessons when they recognized they had encountered gaps in their science content knowledge.

Preliminary questions. General information about a teacher's background and experiences with teaching science, as well as her feelings about the endeavor, are important for setting the context for learning from teaching practice, as indicated in other studies such as Smith and Neale (1989). Preliminary questions about the teachers' background (see Appendix B) addressed: (a) the teachers' previous teaching experience including what subjects they had taught; (b) undergraduate coursework and degrees; (c) type of credential; (d) how useful they perceived their curriculum materials to be; (e) how they generally prepared to teach science; (f) what sources they turned to for support; and (g) their feelings about teaching science. Additionally, I asked teachers about their general approaches to situations, such as when students asked them about something they did not know; when students did not seem to understand what the teacher taught; when lessons went particularly well or poorly; and when they realized they did not know something they needed to know. These preliminary questions provided context for how the teacher thought about and approached her science teaching. They were designed to provide a general idea of how teachers behaved when they realized they did not know a concept they were supposed to teach. Because I did not want teachers to know exactly what I was "looking for" and respond based on what they thought I wanted to hear, I was careful to make sure the questions about the teachers' learning did not seem to be the main foci of these initial questions.

During the first round of observations and interviews I encountered some potential gap indicators that I had not previously thought of addressing in the research. As a result, I asked new preliminary questions at the beginning of the second interview. For example, Ms. Mepps was using worksheets that had incorrect keys during the first visit. Instead of going with her gut feeling about what she thought the correct answers should be, she changed the way she thought about and explained the concepts to support the incorrect answer keys. As a result, I included in the second follow-up interview for all teachers preliminary questions about potential errors in the curriculum. Other preliminary questions in the second follow-up interview related to experiences teachers may have had as they encountered new information preparing to teach, interacting with their students, and dealing with unexpected outcomes in the classroom (see Appendix B for a full list of these questions). Additionally, during the second follow-up interview I asked each teacher if she had had any opportunities to reflect on the lesson I observed during my first visit and asked her to elaborate on those reflections.

General questions about observed lessons. After the preliminary questions, both follow-up interviews included general overview questions about the lessons I observed that day (See Appendix B). I asked the teacher how she felt about the lessons that day; whether everything had gone as expected or if there were any surprises; how confident she was about her knowledge of the science content in the lessons she taught that day and how that level of confidence affected her preparation for and execution of the lessons; and if there were any instances related to the lessons when she encountered something new. I then asked a series of questions about how the teacher had prepared for the lesson she taught that day, including ways that previous lessons may have influenced her preparation. Additionally, I asked if the teacher had experienced any aha moments (insights) while teaching or if she had had an opportunity to reflect on that day's instruction during lunch or a preparation period.

Stimulated recall of observed potential knowledge gaps. After the general interview questions, the interviews shifted to the potential gaps in the teachers' content knowledge I identified in the classroom observations. As noted above, I conducted an initial analysis of the observation before the interview to determine which observed events to view with the teacher and which events to discuss verbally. Viewing and discussing these events during the interview was a form of stimulated recall for the teacher.

In educational research, stimulated recall is used as an after-the-fact introspective self-report research method to investigate cognitive processes by asking teachers to recall or reconstruct their thinking during the episode being recalled. Generally, the source for stimulated recall is videotaped observations of the teacher's own teaching practice. Some variations of stimulated recall, however, also use verbal cues for recall rather than video-recordings. Both verbal- and video-stimulated recall are widely used and accepted methods for studying teacher cognition (Lyle, 2003). According to Lyle, stimulated recall methods occasionally include "a series of structured, but relatively open-ended, questions posed to the subjects" (p. 863). These 'think aloud' questions can assist recall, and need to be asked as soon as possible after, or during, the recall of the event. Although stimulated recall has limitations (such as the inaccessibility of some cognitive processes and the influence of the act of reflection on recall), Lyle contends that "the method has considerable potential for studies into… learning processes, and also for teacher/educator behaviour…" (pp. 861), and that studies can benefit from "minimal intervention in the activity" (p.862). As part of minimal intervention, Calderhead (1981) suggested the necessity of hiding the goals of the research when using stimulated recall techniques so the participants will not inadvertently view the events through the researcher's lens instead of through their own cognitive processes.

My intention in using stimulated recall was to help each teacher reflect on her thought processes during the noted events. I anticipated these reflections would provide additional evidence of (a) whether she had actually encountered gaps in her science content knowledge, (b) whether she recognized these knowledge gaps, and (c) whether she recognized the gaps on her own (at the time it was happening or while reflecting before the interview) or as a result of the follow-up interview process. The potential gap indicators from the observations served as the recall events in the follow-up interviews. Because my research focused specifically on potential gaps in the teachers' knowledge, I selected recall events directly related to potential gaps rather than viewing the entire video with the teacher. This was similar to the salient video *stopping points* that Akerson, Flick, and Lederman (2000) selected (based on specific criteria related to teachers learning from classroom discourse) to recall in follow-up interviews with their teacher participants. As noted above, I used video stimulated recall for up to six of the events and attempted to address the remainder of the noted events verbally. Because of time constraints, however, I did omit some of the events that had initially seemed least likely to indicate actual gaps based on my preliminary ranking. These omitted events were also omitted from further analysis because I was unable to confirm the teacher's thoughts about the events.

During this stimulated recall portion of the interview, we first viewed a video clip of the recall event(s). As part of this process I asked the teacher open-ended probing questions such as "what was going through your mind when this was happening?" or "what were you thinking when the student asked you that question?" or "did you plan on giving that second explanation of the concept to your students?" (see Appendix B). Depending on the events recalled in the video clips, I occasionally stopped the video to ask questions and then resumed viewing the video. Other times we viewed the entire video clip before I asked these probing questions.

In some cases it was clear that the event did not indicate a gap in the teacher's knowledge. For example, in one class a teacher's response to a student question was "I don't know." When we reviewed the event in the interview, she clearly and correctly explained the concept to me and stated that she responded in that way to encourage her student to try to come up with the answer to his question on his own. In such cases I simply moved on to the next event.

However, when a teacher's response to these open-ended questions indicated that she had encountered a gap or when it was still unclear from her response whether there was a gap, I asked follow-up questions. These questions included "could you please be more specific?" or "when did you realize that this was something new?" or "what were your feelings before and after this event?" (see Appendix B). As needed, if the teacher mentioned something briefly, I asked her to elaborate. Based on the teacher's responses, I asked additional questions to help me understand whether she had actually encountered a gap, whether she recognized it as a gap, and when that realization came to her. Additionally, I was aware that the teacher's responses could have resulted from the recall procedure and not necessarily reflected her thought processes at the time of the event. Consequently, after the teacher gave her initial responses and responded to any additional probing questions, I also asked her whether she thought that viewing the video or talking about the events during the interview had changed the ways she thought about the recall events. This process of the teacher comparing her thinking in the interview with her thinking at the time of the event had the potential to help me better determine whether she had recognized the gap at the time she encountered it or if that recognition was influenced by the interview process.

Data Analysis

As noted above, the first phase of analysis took place after each observation in preparation for the follow-up interview. The second analysis phase followed the observations and interviews. I listened to the interviews and viewed the video observations multiple times. I also transcribed the interviews. During some parts of the interview, such as when teachers were listing the courses they had taken as undergraduate students or talking about issues unrelated to their science content knowledge, I summarized rather than transcribing verbatim. In some cases teachers repeated the same words or phrases so I cleaned up the transcript so it would read more clearly without losing any of the meaning. With these few exceptions, the interviews were transcribed verbatim and teacher quotations in the next chapters are direct quotes of what the teachers said in the interviews. I created brief written summaries of events in classroom videos to enable locating those places in the video for further analysis.

After transcribing, I created an analysis table for each visit that listed all the potential gaps I noted in my preliminary analysis (whether or not they were later determined to be actual gaps). In some cases, including my observations of the last classes of the day, there was no video record of the events, only my detailed field notes. Table 3.3 lists example entries from these tables for three teachers. Occasionally, a teacher would talk during an interview about encountering a gap during the observed class that I had not noticed. In these cases I included the events with the previously noted events. During the interviews the teachers also shared experiences when they had encountered gaps in their knowledge that took place prior to my observations. I also listed these gaps in the tables for each visit, keeping them separate for the purposes of potential future data analysis and reporting.

In these analysis tables I noted the video time stamps for each potential gap and then read the interview transcripts to determine whether the events were discussed in the follow-up interview. If they were, I listed the time stamp(s) from the interview transcripts in the table. With this information in the analysis table I analyzed the observation and interview data together to determine whether there was reasonable evidence to suggest actual gaps in the teachers' science content knowledge. If there were gaps I put "yes" in the next column of the table; if it was not

Table 3.3
Examples from Data Analysis Tables

Teacher	Potential Gaps	Addressed in Interview?	Was it a Gap?	Explanation	What Type of Gap	Did teacher recognize the gap?	When was the gap recognized?	Notes
Ms. Beam	Students seem confused about writing 65 seconds instead of 1 minute 5 seconds, so she reiterates that to the class (Video 2.1 Time: 26:38-29:00)	Yes Time: 28:01-30:00	Yes	She stated that she did not anticipate her students would have a problem with that concept	PCK-Knowledge of students	Yes	At the moment it was happening	
Ms. Keller	Teacher says "in other words" to explain a concept in a different way (Video 1.1 Time: 29:40-30:22)	Yes Time: 44:20-46:30	No	Both examples she shared were in the book and she stated that she had previously planned on explaining it both ways	NA	NA	NA	
Ms. Mepps	Teacher cannot find gold (Au) on the periodic table. It is unclear whether she realized Au was the symbol for gold (Video 1.1 Time: 9:07-9:44)	Yes Time: 1:10:38-1:12:22	Yes	She stated that she could not remember the symbol for gold and had to figure it out before she moved on	SMK-facts, nomenclature	Yes	At the moment it was happening	During the second follow-up interview she knew Au was gold's symbol

clear there were gaps I put “no” in the next column. In the following column I provided evidence to support my decisions.

When I confirmed gaps I used the definitions in Table 3.4 to help determine whether the gaps were in PCK, SMK, or both. If a potential gap indicator was determined to indicate actual gaps, it often indicated multiple types of SMK and/or PCK gaps simultaneously. I listed each of these specific types of gaps in the analysis table, but later only listed them as either SMK or PCK. After determining what type of gap was present, I conducted further analysis of the data to

Table 3.4
Science Teacher Knowledge Categories

Subject Matter Knowledge	
SMK- Syntactic	This includes the rules and procedures of engaging in science inquiry (Abel 2007)
SMK-Substantive	This includes facts and concepts, nomenclature, taxonomies, theories, laws, frameworks. It also includes knowledge of how the topic is organized
Pedagogical Content Knowledge	
PCK-Orientations	Ways the teacher approaches teaching science. However, because this is more a subjective choice for the teacher, this was not an area of focus in this study.
PCK-Knowledge of Students	This includes understanding how students may think at this age or level, what common misconceptions they might have, or what kind of background knowledge or experiences they may already have.
PCK-Knowledge of Curriculum	This includes knowledge of materials, how labs are supposed to work (including putting them together properly and understanding the functions of tools for the lab, demo and/or lessons and expected normal (and possibly abnormal) outcomes for the lab) what the correct answers are for worksheets, etc.
PCK-Knowledge of Assessment	This includes understanding how to assess students’ knowledge of science concepts specifically, and understanding science-specific assessment measures in general.
PCK- Instructional Strategies (Science in General or Topic Specific)	This includes specific strategies for presenting or facilitating the learning of science in general or specific science topics.
PCK- Content Representations	Multiple developmentally appropriate ways to represent science content. This includes explanations, demonstrations, analogies, definitions and models used to represent science concepts.

determine whether the teacher recognized the gap(s) in her knowledge that were encountered during teaching, as well as whether the teacher recognized the gap(s) on her own or as part of the interview process. In some cases a teacher may have recognized deficiencies in either SMK or PCK but not the other when it was clear there were gaps in both types of knowledge.

Interrater Reliability

To determine interrater reliability for my coding, I recruited a colleague with a PhD in educational psychology and a background in science education. For training, we worked through the coding process together for a randomly chosen visit. We watched the video clips, read the related interview transcripts, and discussed the coding process in detail. He then independently coded three of the 12 classroom visits chosen randomly.

For this coding, I condensed the information represented in Table 3.3 into a simplified analysis table for each visit. These tables listed all of the potential gaps that were discussed in the interviews. The coding process involved determining whether there was a gap, whether it was an SMK and/or PCK gap, whether the teacher recognized the gap, and whether the teacher recognized it by herself or as a result of the interview process. I also provided the second rater with documents containing all of the relevant sections of the interviews related to each instance as well as video clips of each instance from the classroom observations. We discussed the contents of Table 3.4 in detail by addressing each aspect of SMK and PCK that could be used in the coding process and how I had chosen to code them. For example, curricular knowledge can be either Knowledge of Context or PCK. Although some aspects of learning the curriculum are strictly contextual, many other aspects are specifically relevant to the pedagogy of teaching particular science concepts (PCK). We discussed this difference and I asked him to code PCK whenever there seemed to be a gap in a teacher's knowledge that matched the criteria for "PCK-

Knowledge of Curriculum" explained in Table 3.4. Although I ultimately reported only general SMK and PCK gaps, a more detailed list of different types of SMK and PCK gaps was important in determining the type(s) of gap(s) present.

After the second coder finished coding the three randomly chosen visits, I compared our codes to check for interrater agreement. Although there were some disagreements in our coding, I chose not to focus on complete consensus because the nature of this coding process is somewhat subjective and interpretive. The purpose of the second coder was not necessarily to develop rater training or calibration or to build consensus, but was rather used to demonstrate whether a second party, with minimal training and using the same coding methods and process, would independently assign the same codes. The intent was to show that my coding and methods for coding were reasonable as indicated by the results of a second coder.

A widely used coefficient for this type of simple interrater reliability is Cohen's kappa (Gwet, 2008), which is generally considered to be a better measure of interrater agreement than percent agreements because it accounts for the possibilities of rater agreements occurring by

Table 3.5
Interrater Agreement

	Gaps Y/N	SMK Y/N	PCK Y/N	Recognized SMK gapY/N	Recognized PCK gap Y/N	Recognized Gaps Total
Percent Agreement	83%	80%	92%	91%	87%	89%
Cohen's Kappa Coefficient	0.24*	0.57	0.83	0.80	0.42*	0.66
Probability of Y Response	76%	30%	44%	48%	76%	63%
Probability of N Response	2%	25%	11%	9%	2%	4%
Probability of Error	78%	55%	55%	57%	78%	67%

*Note: Cohen's kappa suggests less agreement than what actually occurred because of the kappa paradox (Feinstein & Cicchetti, 1990) chance. Interrater agreement for this study is reported in Table 3.5 (see Appendix C for the data used to calculate these measures) as both percent agreements and Cohen's kappa coefficients.

As noted in Table 3.5, the percent agreements for each of the rated categories were 80% or better. According to one commonly accepted scale for interpreting Cohen's kappa coefficients (Fleiss, 1981): less than .40 indicates poor agreement, .40-.75 indicates fair to good agreement, and over .75 indicates excellent agreement. Based on this scale the interrater agreement was excellent for whether gaps were PCK and whether teachers recognized their SMK gaps. The interrater agreement was a fair to good for whether gaps were SMK, whether the teachers recognized their PCK gaps and the total number of gaps teachers recognized. As noted in Table 3.5 in two of the categories the Cohen's kappa suggests a low level of agreement because of a phenomenon called the kappa paradox (Feinstein & Cicchetti, 1990).

According to Gwet (2008), "it is a fact that [kappa] coefficients occasionally yield unexpected results in situations known as the paradoxes of kappa" (p. 29). The kappa paradox present in my data was noted by Feinstein and Cicchetti (1990) who pointed out that high interrater agreement is coupled with a low kappa when there is a disproportionately high "prevalence of the observed entity" (p. 543) This can result in an inflated measure of the probability of error which is used to calculate the kappa coefficient. In an instance where data are categorized by "yes" and "no" there is a 50% probability that a rater will code any particular instance by chance. Cohen's kappa coefficients factor that probability out of the raw percentage scores so researchers can measure interrater agreements that limit the effects of chance. In cases of a kappa paradox, however, the equation factors out a disproportionately high level of probability of error. For example, if raters noted the number of Chinese vs. non-Chinese individuals in Guangzhou, China, the number of Chinese would far outnumber the number of non-Chinese. In this case, with the high prevalence of Chinese people, there is a reasonable assumption of high interrater reliability because the data are skewed toward the Chinese individuals. Yet, because the data are so significantly skewed toward one category (Chinese) the Cohen's kappa factors in an increased probability that agreement on whether a person is Chinese is a chance occurrence. This leads to a high correction factor for chance agreement, and therefore the kappa coefficient is inherently low.

Cicchetti and Feinstein (1990) argue that in the case of simple nominal categorization such as the one presented in this study there is no simple alternative reliability measure that can account for or reduce the kappa paradox. Yet they also believe it would be inappropriate to only list the percent agreement in such cases. Therefore, they suggest including the probabilities of the yes and no responses along with Cohen's kappas as evidence of the paradox because these measures "do not have a relatively reciprocal relationship in which one value must rise as the other falls... [and] can each range freely between 0 and 1" (p. 557). Accordingly, Table 3.5 also includes the probability of a yes response, the probability of a no response and the combined probability of error that is calculated by adding the two previous percentages.

Determining whether instances were gaps and determining whether teachers recognized their PCK gaps are the two instances in which the data are skewed to the yes category enough to inflate the probability of error sufficiently to cause the kappa paradox. Especially in the first case, the paradox is evident because each one of the instances I noted for coding was already evidence of a potential gap in a teacher's content knowledge. Therefore it was expected that more instances would be categorized as actual gaps than not. This was the case in my coding as well as the second rater's coding. It is important to note that we did disagree on how to categorize 11 of the 66 instances, but our total percent agreement (both agreement on gaps and agreement on lack of gaps) was 83%. Yet the Cohen's kappa for that category was k= .24, which indicates very poor agreement. However it is also clear the probability of responses is highly skewed toward the yes responses, with a 76% probability of a yes response and only a 2% probability of a no response. If I the agreed upon responses had been evenly distributed between the yes and no categories without changing the disagreements, the Cohen's kappa would have been k=0.67, nearly triple the value of the current k=.24. Factoring in evidence of the kappa paradox suggests that all of the measures of interrater agreement were at least fair to good (and in some cases excellent), an important validation for examining the results of this research in Chapters 4 through 6.

Additional Analysis

After determining which of the potential gaps (observed and/or addressed in interviews) indicated actual science content knowledge gaps, I focused on categorizing the potential gap indicators (including the relevant potential learning triggers) observed during the course of this research. These are presented as brief narratives in the form of mini-cases in Chapter 4, which addresses the results with regard to the numbers of gaps observed as well as the different types of indicators of those observed gaps.

I then conducted analysis on how the depth and nature of each teacher's knowledge seemed to affect her content knowledge gaps. This analysis involved looking for possible relationships between the teachers' preservice post-secondary science coursework and the number of gaps each teacher encountered during each visit. The information about the teachers' preservice coursework was given during the first interview with each teacher and is included in Table 5.1. Initially, this analysis was intended to compare the preservice preparation of elementary certified versus secondary certified teachers. That level of analysis, however, could not be conducted because all of the teachers had secondary certifications. Even so, I felt it was important to see if any lacking coursework contributed to the gaps encountered by any of the teachers.

The next level of analysis entailed comparing the teachers' expressed levels of confidence during each visit to the numbers of gaps they encountered during each visit. During each interview I asked each teacher how confident she felt with the science content she had taught that day. Using their responses I rated their confidence level on a scale of *high, moderately high, moderately low or low*. I then made comparisons for each teacher between the two different visits to see if the teacher's confidence level influenced the number of gaps she encountered from one visit to the other. Because the measure of teacher confidence was subjective, this analysis was conducted strictly within teachers (from one visit to the other) and not between teachers.

The results of how confidence was related to the number of gaps were a good measure for five of the teachers. However, confidence did not seem to explain a large discrepancy in gaps from one visit to another for Ms. Ardis and only seemed to partially explain the discrepancy for Ms. Beam. In both cases it was evident from the observations and confirmed by the teachers that they had not prepared adequately for the lessons they taught on the days they encountered more gaps. Consequently, I then analyzed the potential relationships among confidence, preparation, and gaps. The results of the analyses of preservice preparation, teacher confidence, and daily preparation to teach are addressed in Chapter 5.

All previous analyses focused on the actual gaps I observed teachers encountering. However, the final level of data analysis focused mainly on each teacher's interview responses about her teaching practice in general. Specifically, I focused on teachers' attitudes and practices that seemed to either promote or hinder her learning from teaching practice. This was a shift in data collection and analysis because all of the previous data focused specifically on observed classroom events that were clarified and supported through the teachers' interview responses. The focus on teacher classroom practice that either supported or hindered learning was based mainly on teachers' interview responses with some support from the observations. Consequently, this level of analysis, which comprises Chapter 6, mainly consists of self-report data from the teachers. I examined teacher practices with regard to learning from practice in two main categories: (a) teachers' interactions with their curriculum materials; and (b) teachers' interactions with their students. The data dictated the more specific categories of practices within these two broader categories.

Summary

The methods for data collection and analysis were chosen carefully to specifically address the issues of teachers' science content knowledge gaps in the context of teaching practice. Video-recorded observations of classroom instruction allowed for detailed identification and analysis of the gaps each teacher encountered during her teaching practice. Follow-up interviews provided additional evidence that these gaps were encountered and provided the framework for determining whether the teachers recognized these gaps in their science content knowledge. The processes and tools for determining whether there were gaps and whether teachers recognized those gaps were validated through interrater reliability measures with a second coder. Further, due to the nature of the qualitative design, the nature of the data provided opportunities for additional analysis that may not have been previously envisioned. Chapter 4 details the numbers of gaps encountered, the classroom situations surrounding these science content knowledge gaps, and whether the teachers recognized these gaps. Chapter 5 addresses teachers' prior knowledge with regard to gaps by specifically examining each teacher's post-secondary coursework, confidence in their knowledge of the classes they were observed teaching, and daily preparation to teach. Chapter 6 addresses interview responses and observations of practice that may have related to the numbers of gaps teachers encountered and how many of those gaps they recognized.

CHAPTER 4

GAPS IN TEACHERS' SCIENCE CONTENT KNOWLEDGE

The overall purpose of this research was to determine when early-career middle-school science teachers recognize gaps in their own content knowledge. The teacher observations and interviews were conducted with specific emphasis on (a) what classroom events can potentially indicate gaps in teachers' content knowledge; (b) what types of classroom events can trigger teachers' recognition of their science content knowledge gaps; (c) how the depth and nature of a teacher's knowledge can affect their science content knowledge gaps; and (d) what teaching practices can help teachers better recognize and address gaps in their science content knowledge. This chapter addresses the first two research subquestions by detailing the observed classroom events when the teachers in this study encountered gaps in their science content knowledge, identifying what classroom events were indicators of the observed gaps, determining the nature of these gaps, and determining whether the teachers recognized the gaps. The chapter begins by describing the frequencies of observed gaps and the processes of identifying and determining the nature of the gaps as well as determining whether the teachers recognized them. This is followed by categorizing the potential gap indicators into a typology for identifying potential science content knowledge gaps which is described as brief narratives in the form of mini-cases. The chapter concludes addressing the issue of what classroom events can potentially trigger teachers' recognition of gaps.

Identifying Gaps in Teachers' Science Content Knowledge

As described in Chapter 3, during each observation I identified and noted *potential gap indicators*, which are observable behaviors or events in the classroom that suggest possible gaps in the teacher's science content knowledge. These indicators can include teachers' behaviors and reactions to potential triggering events such as student questions, student responses, teacher responses, and so forth, but do not include all occurrences of these events. Generally, if a student answer seemed to be what the teacher was expecting or the teacher seemed completely unfazed by a student question, the event was not noted. However, when the teacher paused before giving an answer, seemed surprised by a student question or response, looked information up, and so forth, the events were noted as indicators of potential gaps in the teacher's science content knowledge. Table 4.1 lists the frequency of these events noted as potential gap indicators for each observation. Overall, over the course of 12 visits (two per teacher), I noted 151 classroom

Table 4.1
Frequencies of Observed Events Indicating Potential Gaps

Teacher/Visit	Events from Observed Classes*	Events Indicating Gaps	Percent of Events Indicating Gaps
Lane/1	4	1	25%
Lane/2	11^	8	72%
Ardis/1	10	5	50%
Ardis/2	22^	21	95%
Kidd/1	2	2	100%
Kidd/2	7	5	71%
Keller/1	20	12	60%
Keller/2	12	6	50%
Beam/1	15	15	100%
Beam/2	18^	13	72%
Mepps/1	23	22	96%
Mepps/2	7	4	57%
Total	151	114	75%

* Including those brought up by the teacher but not previously noticed by the observer
^Indicates observations where multiple events were indicators of the same potential gaps and were grouped together in later analyses.

events that potentially indicated gaps in the teachers' science content knowledge. During interviews the teachers brought up an additional eight instances that I had not previously noticed during the observation or preliminary analysis. After follow-up interviews with the teachers, where most of these events were discussed in detail, I determined that 114 of the 151 events

(75%) indeed revealed gaps in the teachers' science content knowledge (see Table 4.1). This process of determining whether the noted events (both from the observations and interviews) actually indicated science content gaps was validated with an 83% interrater agreement (see Table 3.5).

As noted in Chapter 1, I defined gaps in science content knowledge as the gaps between the teacher's actual level of content knowledge and what they needed to know to effectively teach the science content to their students. The most obvious kind of gap I observed was a teacher making an error when explaining a concept, theory or law, such as telling students that aluminum and lead can be separated magnetically. Other observed gaps included having limited understanding of student thinking or a need for alternative explanations of some concepts. In order to accurately recognize and label the science content knowledge gaps I observed, I entered the classrooms with at least a basic understanding of the concepts being taught. I then followed up with additional research to confirm my suppositions and clarify any uncertainties. It is important to note that although some gaps, such as content errors, were easily visible, the evidence of other gaps became apparent only when learning took place and the gap had already been filled. For example, Ms. Keller came up with an alternate on-the-spot explanation of power using an example of cutting the same piece of wood with a chainsaw and a hand saw because her students did not seem to clearly understand the textbook definition she had given them. She explained in the interview that she had not thought about explaining it in that way before but had a moment of insight in the classroom when she realized her students needed it explained in a different way. Because I could only observe her actions and not her thoughts, I was only able to infer the possibility of it being an on-the-spot alternative explanation that she had come up with because she had encountered a gap in her knowledge. That supposition was confirmed while discussing the event in the interview.

Teachers' SMK and PCK Gaps

The gaps I observed, noted, and confirmed fit into two broad categories: subject matter knowledge (SMK) and pedagogical content knowledge (PCK). SMK gaps directly connect with the syntactic and substantive content of the science subject. I labeled gaps as SMK gaps when it was evident that the teacher had misconceptions about the concepts she was teaching. This was often apparent when the teacher made content errors in class or expressed to her students or to me that she was unsure of the "facts." For example, an SMK gap occurred when Ms. Mepps gave the definition of carbonation to describe humidity.

PCK gaps relate to how to teach the science content (see Table 3.4). I labeled gaps as PCK gaps when teachers were unfamiliar with the curriculum materials, did not understand the procedures for or possible unanticipated outcomes of inquiry activities, learned something new about student thinking, or needed an alternate way to explain a concept. Examples of PCK gaps include when Ms. Lane realized a picture she was using to illustrate the respiratory system did not have enough detail (PCK-content representations), when Ms. Keller did not realize some of her students did not understand what the word neutral meant (PCK-knowledge of students), and when Ms. Ardis was unsure how to correctly set up an inquiry activity about fulcrums and levers (PCK-knowledge of curriculum).

As noted in Table 4.2, of the 106 observed classroom events that indicated actual gaps in the teachers' science content knowledge (some of the original 114 events in Table 4.1 were combined in later analysis because they were indicators of the same gaps), 52 indicated SMK gaps and 83 indicated PCK gaps. In many cases the same classroom event indicated both SMK and PCK gaps. For example, in response to a student question, Ms. Mepps spontaneously grabbed a plastic bottle on her desk with different sized particles in it to try to demonstrate how objects can be separated by weight. She quickly realized that the representation was not working for what she was trying to demonstrate (a PCK-content representations gap) but did not seem to realize that what was happening was an example of filtering by size. This was an SMK gap because she did not seem to understand the process of filtering by weight enough to recognize an example of it. Additionally, because she did not recognize the demonstration as a representation of filtering by weight she also had an unrecognized PCK-content representations gap in that regard.

Table 4.2
Frequencies of Observed SMK and PCK Gaps

Teacher/ Visit	Events Indicating Gaps*	SMK Gaps	N Recognized (%)	PCK Gaps	N Recognized (%)	Total Gaps
Lane/1	1	0	NA	1	1 (100%)	1
Lane/2	6^	3	3 (100%)	4	4 (100%)	7
Ardis/1	5	2	1 (50%)	4	3 (75%)	6
Ardis/2	17^	10	6 (60%)	16	13 (81%)	26
Kidd/1	2	0	NA	2	2 (100%)	2
Kidd/2	5	0	NA	5	5 (100%)	5
Keller/1	12	7	6 (86%)	9	9 (100%)	16
Keller/2	6	2	1 (50%)	5	3 (60%)	7
Beam/1	15	9	5 (56%)	12	9 (75%)	21
Beam/2	10^	3	2 (67%)	9	9 (100%)	12
Mepps/1	23	15	9 (60%)	13	9 (69%)	28
Mepps/2	4	1	1 (100%)	3	2 (100%)	3
Totals	106	52	34 (65%)	83	69 (83%)	135

*Including those brought up by the teacher but not previously noticed by the observer
^Some events from Table 4.1 were grouped together because they were indicators of the same gaps

Typology of Observed Potential Gap Indicators

The main focus of the research was identifying the classroom events that illuminated gaps in teachers' science content knowledge and had the potential to trigger learning. Table 4.3 summarizes a typology listing the types of potential gap indicators observed in the study and found to indicate actual gaps. The elements of this typology are detailed in the sections below.

Table 4.3
Observed Indicators of Teachers' SMK and PCK Gaps

Types of Observed Gap Indicators	N of Teachers	N of Gap Indicators*	SMK Gaps	N Recognized(%)	PCK Gaps	N Recognized(%)
Teacher Instruction						
Teacher looks up information in class	3	4	1	1 (100%)	3	3 (100%)
Instructional Inconsistencies						
Changes in lessons	5	7	2	2 (100%)	7	6 (86%)
Incongruent content	3	4	0	NA	4	0 (0%)
T Errors in class	5	22	19	8 (42%)	13	5 (38%)
T Errors in interview	3	4	4	2 (50%)	0	NA
Need alternate explanation/ representation in class	4	6	0	NA	6	6 (100%)
Aha moment	3	5	0	NA	5	5 (100%)
Issues w/curriculum (errors, inconsistent)	4	13	9	6 (67%)	11	7 (64%)
Unexpected Outcomes	2	17	8	7 (88%)	15	14 (93%)
Student Input						
Student Errors	4	5	3	1 (33%)	5	2 (40%)
Student Question	4	18	14	8 (57%)	9	6 (67%)
Student Response/Idea	6	12	6	4 (67%)	8	7 (88%)
Inconsistent student data	1	2	1	0 (0%)	2	2 (100%)
Dismiss Plausible Student Idea	2	3	3	0 (0%)	3	0 (0%)

*Sometimes the interchanges between students and teachers were counted as singular events in Tables 4.1 and 4.2, but they were separated by teacher and student actions in this table because often multiple aspects of those events illuminated the gaps.

It is important to note that many of the observed knowledge gaps in the classroom potentially involved more than one learning trigger or gap indicator concurrently. For example, in some cases a potential learning trigger (such as a student question) coincided with a potential gap indicator (such as the teacher looking up information to answer the question). In essence, the teacher's behavior after the student question was an indicator that there was a gap in the teacher's knowledge as well as an after-the-fact indication that the student question was a learning trigger. In other cases the learning trigger was metacognitive and not observable (like a moment of insight/aha moment), but the teacher's behavior (such as telling the students she had just thought of a new way to explain something) was an indicator that there had been a gap that was filled by the insight. In some cases the potential learning trigger and potential gap indicator were the same (such as a teacher error or unexpected outcome of a lesson). Consequently, because many of the observed knowledge gaps in the classroom involved more than one learning trigger or gap indicator concurrently and each one was listed under its own category, the numbers of events/indicators does not align with the frequencies in Tables 4.1 or 4.2. Likewise, because many events/indicators illuminated both SMK and PCK gaps, often the sum of PCK and SMK gaps is greater than the number of events. Conversely, in some cases the same event illuminated multiple SMK or PCK gaps but the data only list whether SMK or PCK gaps were present, not how many of each were observed.

The observed potential gap indicators (classroom events) are discussed in the sections that follow and listed in the first column of Table 4.3. They fit into two broad categories: (a) teacher instruction and (b) student input. The second column of Table 4.3 contains the number of teachers who encountered knowledge gaps as a result of each type of event. The third column presents the number of each type of potential gap indicator encountered across all teachers. The fourth through seventh columns present how many gaps were SMK or PCK, and how many of each type of gap were recognized by the teachers.

Observed Gap Indicators Related to Teacher Instruction

Many of the classroom events that indicated gaps in teachers' science content knowledge were directly related to the teachers' own actions during classroom instruction. These events are listed in the upper sections of Table 4.3 and described below using examples from the observed classes.

Teacher looks up additional information. Three of the teachers looked up information during instructional time in class, indicating they had encountered gaps in their knowledge. Not surprisingly, because looking up information was an observable behavior of the teacher attempting to bridge gaps she had already recognized, the teachers recognized all of the gaps associated with this gap indicator. For example, Ms. Beam read silently from the lesson manual as class was starting and then read the text word for word to introduce the activity and its related science concepts to her students. When questioned about this occurrence, said she had been reading the background information and getting the information on how to prepare the activity as class was starting. She also explained that she had read the text verbatim to "make sure I laid down that background information and… make sure that I'm not leaving out anything important." Although this did not necessarily indicate any subject matter knowledge gaps, Ms. Beam was aware that her knowledge of the curriculum was not as extensive as she would have liked it to be.

In another instance, I observed Ms. Mepps looking at the label of a bottle of rubbing alcohol during class. When questioned about it she said she had previously asked another teacher what was in rubbing alcohol and they had looked it up. She further explained, however, that she had read the label in class because she was “double checking to make sure I didn’t tell them something wrong.” In that instance, which indicated an SMK gap but not really a PCK gap, she was fairly confident in her knowledge but not quite enough to risk giving her students misinformation, so she confirmed it by reading the label in class.

Instructional inconsistencies. Inconsistencies in how a teacher presented content to her students represented another gap indicator. During observations I noted two types of these inconsistencies: (a) altering or changing the lesson in some way from one class to another; and (b) representing content in different or seemingly incongruent ways that could be confusing to students during a lesson. I observed 11 instances in which inconsistencies in a teacher’s instruction to her students indicated knowledge gaps. The teachers recognized all but one of the instances in which the inconsistency was a change in their lesson from one class to another, but the teachers did not independently recognize any of the four instances in which they represented the content incongruently. Although none of the observed instances of incongruent content were indicators of SMK gaps, each instance had the potential to confuse students and was classified as a PCK gap.

Changes in lessons. In the case of changes observed across lessons, the changes were after-the-fact indicators of teachers’ knowledge gaps. The gap was evident because the teacher had changed her instruction in some way to address or bridge it. Changes in lessons occurred in two different ways: (a) the teacher deliberately omitted the content from later classes that day; or (b) the teacher made an effort to bridge the gap by adding previously unplanned new content or giving additional in-depth explanations to her students.

Omitting content. During the first visit to Ms. Keller she showed her classes a video about different types of energy. During the first class of the day she finished the video and started going through a PowerPoint presentation of notes on the topic. During the last class of the day she ended the class instruction with the video and did not use the PowerPoint presentation even though there was time to do so. When questioned about the differences between the two classes, Ms. Keller said she chose not to show the PowerPoint after the first class because she realized she was not as comfortable with the information as she had previously thought she was. “I have to go back and look this stuff up myself… and reexamine what exactly I know,” she said. She added “I’m still not 100% sure what specifically we’re going to cover in this unit, like how in-depth to go with this… Conceptually, maybe to be able to explain it, I need to go back and review.” Because Ms. Keller was concerned about her understanding of the concepts as well as how she was going to present and those concepts, this experience illuminated both SMK and PCK gaps.

Adding content. Additionally, during her later classes, Ms. Keller explained that she took more opportunities during the video presentation to pause the video to facilitate classroom discussions of the concepts. Although part of her rationale for doing this may have been a need to stretch the time the video took so there was not time to get to the notes, Ms. Keller explained that throughout the day students had asked questions during the video so she stopped and discussed the video at those points during those classes and in subsequent classes. She also added that the more times she watched the video throughout the day the more ways she saw that she could apply it to what they were talking about.

In another example, Ms. Ardis’s students were doing an inquiry activity based on simple machines and energy transfer. Their goal was to light a small light attached to a small motor by rubbing the motor along a rubber band stretched over a textbook. A student in her first class suggested that they could test it by rubbing the motor slowly and then rubbing it fast to see which experimental condition would light the light. During a later class period, Ms. Ardis suggested that a group of students should rub it fast and then rub it slowly to see which condition would light the light better. As a result of this student suggestion Ms. Ardis had changed the way she approached the lesson in her later class periods.

Incongruent content. Presenting incongruent content did not necessarily indicate SMK errors, but was more of a PCK issue related to explaining concepts clearly enough to avoid confusing students in the class. Each of the four observed instances of three teachers presenting content incongruently indicated gaps in PCK-representation and did not seem to indicate that the teachers did not understand the concepts (SMK gaps), and the teachers did not recognize these PCK gaps in any of the observed instances. For example, while explaining subatomic particles (protons, neutrons, and electrons) Ms. Keller showed a PowerPoint slide displaying models of three different atoms. Two of the models had red protons and blue neutrons, but it was clear she had colored the proton red in the third model (a Hydrogen atom) on the slide. When a student asked about the colored proton, Ms. Keller responded that the protons were red in the two other models, so she colored it so they would all look the same. On the next slide, however, there was a model of an atom with blue-colored protons and red-colored neutrons. Clearly protons and neutrons are not red or blue, and the models she used were simplified representations of the complexities of subatomic particles. Although none of the models were inherently problematic, the discrepancy in her representations of the atom models was potentially confusing to her students. Interestingly it was the same discrepancy she was trying to avoid by coloring the proton on the hydrogen atom red. During the follow-up interview Ms. Keller explained that her intention was to have uniformity among the three models on the same slide and that she was not concerned about uniformity in the rest of the presentation. Her decision did not seem to take into account the possibility that the conflicting representations on other slides could potentially confuse some students.

In another example, Ms. Lane was teaching her students about base pairing in DNA and RNA and consistently correctly said “there is no Thymine (T) in RNA.” However, many of her students became confused while attempting to answer questions about what bases would pair together in DNA and RNA because Ms. Lane frequently seemed to contradict herself by asking “what binds with T in RNA?” and “what pairs with the T in RNA?” When she recognized the students’ confusion, she simply repeated the procedures more slowly and loudly rather than representing the content in a different way. This did not seem to be an SMK error because Ms. Lane clearly knew the base pairs for DNA and RNA. Yet the way she structured the activity was confusing because every time there was a T in the original DNA strand and the students were asked to write down the corresponding RNA base “pair”, Ms. Lane used wording (noted above) that made it seem as though there was a T in RNA. In the interview Ms. Lane said that she had assumed her students were just trying to get out of doing the activity by not listening to the procedures, and it was not until she watched and discussed the video that she recognized the possibility that they were confused by the way she was phrasing her questions.

Teacher classroom errors. One clear indicator of a science content knowledge gap was when a teacher made a content error during classroom instruction. Because the teacher was making an error it was often because she was unaware of her own misconceptions. It was not surprising, therefore, that for the teacher content errors I observed, teachers recognized their SMK gaps only 42% (8/19) of the time and PCK gaps only 38% (5/13) of the time. It is important to note that 12 of the 23 examples of teacher content errors came from the same teacher, Ms. Mepps, with the remaining 11 examples coming from four other teachers. Some of

Ms. Mepps's errors, however, can be attributed to an incorrect answer key she was given by another teacher, an issue discussed in a later section.

SMK errors. SMK errors occurred when a teacher misstated facts or demonstrated that she did not fully understand a concept. For example, Ms. Lane told her students that the Heimlich maneuver was used to get food out of the esophagus (digestive tract) instead of correctly stating that it was used to remove objects blocking the trachea (airway). She clearly told her students that she was unsure if she had explained it correctly, and in the interview she said she had been thinking, "but is that getting out of the esophagus or the trachea?" When questioned about which was correct she simply said "I have to see."

In another instance, Ms. Mepps was unable to find gold (Au) on the periodic table in her classroom. Even though it did not seem particularly relevant to the lesson, she looked through the periodic table on the wall from across the room until she saw "gold" under "Au." In the interview she confirmed that she had not remembered that Au is the symbol for gold. As she put it "you know it is one of those random ones and when I first… looked up I actually though it was silver [Ag], and I was like 'that is not what it is. I know it is A-something.'" She conceded that she could have just moved on without figuring it out, but she also knew it would drive her crazy until she knew what the actual symbol was.

Interestingly, there was one case when Ms. Keller only thought she had made an error, but that realization helped her recognize she was unsure of her knowledge about the subject. She was discussing the symbols of elements with her students, and she stated that lead is Pb for the Latin word "plumbum" and that plumbers got their names because pipes used to be made of lead. Then she said, "they might be. I may be incorrect on that." In the interview she explained that she was unsure whether any pipes were, in fact, still made of lead and determined that she needed to find out for sure before explaining what she was thinking any further. Even though her statements were technically accurate, the SMK gap was related to her being unsure of the accuracy of that knowledge.

PCK errors. PCK errors occurred when teachers used representations or demonstrations that did not adequately represent the concept they were trying to explain or when teachers demonstrated that they were unfamiliar with the curriculum materials for the lesson they were teaching. These are different from examples of teacher inconsistency because in those instances the representations were appropriate, but the teacher's explanations were potentially confusing. The two main categories of observed PCK errors were content representations and knowledge of curriculum materials.

Content representation errors. Content representations errors occurred when a teacher's demonstrations or representations did not actually demonstrate or represent what she thought it would. For example, during my second visit a student asked Ms. Mepps how to determine the state of matter for the earth's inner core, and she asked him if it was a solid or a liquid. The student incorrectly replied that it was both a gas and a liquid. Ms. Mepps then asked him if a basketball is a solid or a liquid. While watching the video clip during the follow-up interview, Ms. Mepps stated that she came up with the basketball representation because she saw a basketball on the student's shirt and immediately thought "basketball equals solid." However, she also explained that she realized the basketball was not the best analogy to use because it was only solid on the outside, and she mentioned other possible representations that she thought would have worked better.

Ms. Mepps had another PCK error during the first visit with her. She was talking with her students about different ways to separate mixtures. A student asked if water was necessary to separate something by weight, so she looked around the room for something she could use to demonstrate separation by weight without water. First she grabbed a binder and a piece of paper and asked him if he could tell which one was heavier. Then she noticed a bottle full of different sizes of plastic beads and salt that was sitting on her desk. She grabbed it and started shaking it, expecting that the larger heavier beads would settle to the bottom. The smaller particles, however, settled to the bottom, which was exactly the opposite of what she was trying to demonstrate. When she watched the video she said:

> I was kind of like, "oh, plan failed" because I didn't think about the fact that the beads have holes and a lot of area and the salt is going to be able to fall and go through all those cracks and go to the bottom. That is why I was trying to flatten it out and make it go to the bottom and it didn't. That is why I kept shaking because I was thinking "ahhh this isn't working the way it is supposed to be. I thought the denser heavier stuff would go to the bottom and it's not." Whoopsie!

She then explained that she had realized that the smaller particles like the salt would go straight to the bottom "no matter which one is heavier or denser." At this point it seemed to be becoming clearer to her that the model she was using was a good example of filtering by size rather than density so I asked if she had thought about it in that way. She paused and then responded: "not really until just now, but that makes sense… Now I can make that connection in my next classes." As mentioned earlier, in this instance Ms. Mepps's use of the wrong model for what she was trying to explain and the fact that she did not clearly see what the model was actually demonstrating indicated both SMK and PCK gaps, and could be categorized as both SMK and PCK errors.

Knowledge of curriculum errors. Teachers also made PCK errors in their classes when they clearly demonstrated that they did not know the curriculum or materials well enough. For example, during one of Ms. Beam's labs she did not know the exact ratio of water to solid copper sulfate powder needed to make a copper sulfate solution for her battery lab. She simply poured some of the copper sulfate powder into a pitcher of water and started stirring. When the lab did not work properly for any of her students, she told her class that it may have been because she had mixed too little or too much copper sulfate powder into the water. In another instance, Ms. Ardis was trying to help her students balance a fulcrum and lever attached to a pegboard that had different numbers of metal washers on each side of the lever. The directions for the students clearly stated where the fulcrum should have been located on the pegboard (including a picture), and the main reason they could not get it to balance was because they had their fulcrum in the wrong position. Instead of seeing that error, the teacher kept moving the washers back and forth trying to get it to balance, which was impossible without first placing the fulcrum the correct position. In this case, although there was also evidence of an SMK gap, it was mainly apparent because Ms. Ardis was not familiar enough with the curriculum to recognize when her students had constructed the inquiry apparatus incorrectly.

Teacher needs an alternate explanation or representation for a concept. Ms. Mepps's on-the-spot alternate representation of separating something by weight was also an example of when teachers recognized gaps in their PCK and realized they needed to provide their students with different or alternate explanations or representations of concepts. I observed this type of indicator six times with four teachers; each time the event was an indicator of gaps in the teachers' PCK, specifically with regard to their knowledge of content representations. Additionally, all of these instances were examples of observing after-the-fact evidence of a gap because the teacher had already done something to bridge the gap, so it is not surprising that the teachers recognized the gaps in each of the six observed instances. One example of this occurred when Ms. Lane’s students were drawing life-sized models of the human body and asked her the best way to draw the heart and lungs together. She was leafing through the textbook but did not find what she was looking for so she went to the computer and found an image of the heart and lungs together to show the students. Later in that same lesson Ms. Lane realized that some of the images in her power point presentation did not have enough detail, so during her planning period she found different images online. Specifically she said:

> I was trying to show them how the branching of the trachea went and all I had was a picture of an opaque lung so they didn’t see any of the branching besides the initial three (the two going to the right and the one going to the left), so I think it would be hard for me to visualize the concept of these branching out if that was all I had to look at, so I [found] some pictures that showed the branching clearer and preferably labeled them too.

Ms. Lane’s decision to find more detailed pictures was also an example of the changes in lessons described in a previous section.

In another example, Ms. Keller came up with an on-the-spot explanation of power when she was explaining the concept to her students. She explained, “power is the rate at which energy is transferred, or the rate at which work is done.” Then she gave a seemingly impromptu example:

> If you’ve seen a logging completion… some of them use handsaws and some of them use chainsaws. Now technically they use the same amount of energy to get through the same piece of wood. So in other words, regardless of whether I’m sawing it manually or whether I’ve got a chainsaw, they both use the same amount of energy. However, they

don't have the same amount of power. The chainsaw can cut through that wood faster, so therefore the chainsaw has more power…

When asked how she came up with the idea she said she had not planned it and she just pulled it out of nowhere at the moment she needed it.

Aha moments/insight. The impromptu explanation of power Ms. Keller gave her students in class was also an example of a moment of insight, or aha moment. I used Sandkuhler and Bhattacharya's (2008) research on insight and their definition of a "cognitive problem," to define content knowledge gaps for this research. Their research focused on how insight, or aha moments, can be the solution to cognitive problems. In my preliminary study (Kinghorn, 2008), I specifically asked teachers about their aha moments, but I was unsure whether I would actually observe any aha moments in the current study given the limited time spent observing each teacher. Although I did not observe any aha moments that bridged SMK gaps, I did see five instances of aha moments bridging PCK gaps with three of the teachers. Additionally, because a moment of insight generally occurs as a gap is being consciously bridged by the teacher, it was not surprising that the teachers recognized all of the gaps in their knowledge indicated by moments of insight.

Two of the aha moments occurred during my second observation of Ms. Kidd when her students were making structures to test potential damage from different types of simulated earthquakes. After one group brought her a structure that had Popsicle sticks arranged and glued together in a log cabin formation, Ms. Kidd made a connection to Lincoln logs. When asked about it in the interview, she stated that she had not thought about that before and "the way they had their popsicle sticks glued together made me think of that and how much better it would be if there was a groove that fit in there… I wanted them to… think of that." She had a similar experience talking about crossbar supports for the structures. When asked if that was also something that just came to her in the moment, she said “yes, a lot of things just come up at the moment for me.”

Another aha moment was observed when Ms. Mepps was talking about compounds and said “ooh” followed by another definition for a compound. In the interview she explained that if she ever said “Ooh!! Oh, wait!!” in the classroom, “that was never the original plan.” She added that she sometimes had random thoughts pop into her head that she could not explain and that when students had asked her questions she would play back in her mind what she had previously taught them and what examples she had previously given in class so she could try making more connections.

Issues with curriculum. Another indicator of gaps in teachers’ science content knowledge is related to issues with their curriculum materials. I observed gaps in teachers’ knowledge related to two types of curriculum problems: incomplete or inconsistent information in the curriculum materials; and errors in the curriculum materials. The teachers recognized less than 70% of the gaps associated with curriculum inconsistencies or errors.

Incomplete or inconsistent information in curriculum. I observed seven instances (from five teachers) of incomplete or inconsistent information in the curriculum. In one example, one of Ms. Mepps’s students asked her about the temperature of the Earth’s inner core. Ms. Mepps responded to the entire class that she was not sure what the temperature was or if it was even in their books. In the interview she confirmed that the information was not in the textbook or notes and she would have to go look it up elsewhere. Another example of incomplete information in the curriculum occurred when the pictures of the heart and lungs in Ms. Lane’s textbook did not show all of the details she thought her students needed to understand these organs and how they are situated and work together.

There were also some instances where the information in the curriculum materials was inconsistent. For example, when Ms. Ardis was doing an activity where her students were supposed to determine the pH of different substances based on clues she gave them. One of the substances was hand soap, with a pH of 8, and another was soapy water, with a pH of 12. Earlier in the class Ms. Ardis had helped her students logically come to the conclusion that if water was added to an acid the pH would get closer to neutral (pH 7). The same is true for water added to a base. It seemed inconsistent that soapy water would be more basic than plain soap. One simple explanation for this seeming discrepancy is the difference in pH between hand soap and stronger chemical detergents. The directions and materials for the activity did not make this distinction, however, so there was no immediate way to know what kind of soapy water the activity was referring to. Ms. Ardis did not recognize this discrepancy until we discussed it in the follow-up interview and she determined to contact the individual she had obtained the activity from to ask for more detailed information.

In another example of inconsistencies in the curriculum materials, Ms. Keller showed a video about different types of energy and then went through class notes on the subject using a PowerPoint presentation derived from the information in the class textbook. However, the list of energy types in the video had some different names than the ones from the textbook (see Table 4.4). Ms. Keller pointed this out to her students but made it clear to them that the types of energy were exactly the same thing with different terms to define them. The problem of different terms for the same types of energy became apparent when Ms. Keller realized she had put nuclear energy down twice on her power point but was unable to easily figure out which type of energy

Table 4.4
Differences in Energy Terms between Video and Power Point Presentation

Video	PowerPoint
Heat	Thermal
Mechanical	Mechanical
Nuclear	Nuclear
Radiant	Electromagnetic
Chemical	Chemical
Electrical	Electrical
Sound	???

(sound) was missing. Additionally, during the interview she easily labeled heat and thermal energy as the same but mistakenly said that electromagnetic energy was also a form of heat energy when it should have been paired with radiant energy. In addition to the inherent problems with different terms defining the same types of energy, this disconnect also illuminated a gap in Ms. Keller's SMK about radiant and electromagnetic energy when she made an error she did not recognize in the interview.

Errors in the curriculum. For one teacher, Ms. Mepps, I also observed instances in which the curriculum and materials she was using had incorrect information. The lesson was about the differences between mixtures, compounds, and solutions and ways that mixtures can be separated. Ms. Mepps was using worksheets passed on to her by another teacher in the school without any official answer keys. The other teacher had filled in the answers and Ms. Mepps had written her own answer keys based on those answers.

One of the worksheets required students to separate a list of substances such as coffee, ink, blood, and sand into columns representing mixtures, compounds, and solutions. By design the worksheet had inherent problems that seemed to exacerbate the issue of the incorrect answer key. First, all solutions are mixtures but not all mixtures are solutions. Second, some of the substances listed could plausibly fit into more than one column. Unlike the distinction made between alcohol (a compound) and rubbing alcohol (a solution of alcohol and water) on the worksheet, there were no distinctions made for ammonia or coffee in this chart so it was unclear which column each substance was "supposed" to go in. Ammonia was problematic because household ammonia (ammonium hydroxide) is a solution, but Ammonia (NH3) is a compound. Additionally, coffee was listed on the key as a mixture even though Ms. Mepps and many of her students thought it should be a solution. To reconcile the difference Ms. Mepps appropriately explained to her class that coffee grounds are a mixture but coffee dissolved in water is a solution, so coffee could reasonably fit in the mixture column.

Although labeling some of the substances was inherently problematic, there were other substances—air, water, and sugar water—that were clearly a mixture, a compound and a solution, respectively. Humidity, however, which is a mixture of air and water, not a solution with air dissolved in water, was incorrectly listed as a solution on Ms. Mepps's answer key. Although Ms. Mepps was able to adequately come up with an acceptable alternate explanation for why coffee was listed as a mixture instead of a solution, she had much more difficulty with humidity when her students disagreed on what column it belonged in.

At one point in the lesson a student asked her if humidity is part of the mixture of air. The student was correct, but Ms. Mepps told him it was a solution because air is dissolved in water. In the interview she said the other teacher had explained that it is a solution "because it is air mixing with water." As Ms. Mepps put it, "I was like, 'that makes sense.'" Because what she was describing was really consistent with carbonated water (carbon dioxide dissolved in water), I asked her about it. She responded, "I don't know what carbonation is. I just know it is called soda water..."

On Ms. Mepps's other worksheet where students were supposed to determine the best way to separate two substances, the answer key incorrectly stated that magnetism (not weight) would be the best way to separate aluminum and lead pellets. In class Ms. Mepps told her students it could be done using magnetism or weight. During the interview she clarified her response by saying "the answer key says it is supposed to be magnetism. I thought weight because I knew lead was a lot heavier than aluminum." However, even after a student said he had worked with both metals in his father's shop and that neither one was magnetic, she continued to accept both magnetism (the incorrect answer on the key) and weight (the correct answer) as a plausible. Even though both she and her students thought weight was the correct answer, she still felt a need to accept the incorrect answer from the key.

Unexpected outcomes of lessons. Another way that two of the teachers encountered gaps in their science content knowledge was their classroom experiments not turning out in the ways they expected. The two teachers who encountered gaps due to unexpected outcomes recognized all but one of the associated SMK gaps and all but one of the associated PCK gaps. As mentioned earlier, Ms. Ardis had issues with the fulcrum inquiry activity when it did not work the way intended. Additionally, during that class some of the other inquiry apparatuses did not work the way the book explained they would, which required some additional classroom troubleshooting and pushed Ms. Ardis to the edge of her knowledge about the subject matter and curriculum.

The most compelling examples of unexpected outcomes, however, occurred when Ms. Beam's class was engaged in a battery lab from a district provided kit. The investigation included small rectangular sheets of copper and zinc metal with blotter paper between them. This apparatus was held together with a rubber band and placed into a beaker filled with a copper sulfate solution. The ends of the two metal sheets were bent away from each other at the top and a wire for a small light bulb was taped to each one, creating a closed circuit. During the observation of the first class of the day it was clear Ms. Beam had not prepared the lesson before she class started. As mentioned previously in the PCK errors section, one of the first things she did in class was open a sealed bottle of copper sulfate and pour an unmeasured amount of it into a pitcher of water to make the copper sulfate solution. Additionally, as also mentioned earlier, she read the directions and background information word for word from the book. When her students had put together their batteries and placed them in the solution, the first surprise to Ms. Beam seemed to be that the zinc oxidized in the solution and turned black almost immediately. When questioned about it in the interview she said, "It was a surprise to me that it turned as quickly as it did. I knew that it would, but it was just like immediate, as soon as they put it in the solution it immediately turned [black]." She referred back to the one time she had done the activity in professional development training when she remembered the zinc not oxidizing so quickly. She then suggested that she probably put too much copper sulfate powder in her solution, which made it more concentrated.

The next surprise seemed to come when, nearly five minutes after all of the groups had put the copper and zinc into the solution, Ms. Beam asked the class if any of their lights had lit up yet. When she determined that none of them had lit, she started troubleshooting the experiment by re-taping the wires attached to the lights with some of the groups in an attempt to figure out why it was not working. As she put it, she was "looking at their procedure and… there were a couple of minor things, but for the most part it appeared they had set it up correctly and I was just wondering why it hadn't worked yet." At that point her troubleshooting switched to adjusting the amount of tape holding the wires onto the zinc and copper plates as well as changing the location of where the wires were taped on the zinc and copper. She also made sure she had the positive and negative wires connected in the right places. When none of these changes fixed the problem, she suggested to the class that the fact she had not mixed the copper sulfate solution correctly may have had something to do with the problem, and she also asked her students for additional ideas about why it may not have worked. One student very astutely noticed that the blotter paper between the copper and zinc was still dry when her group took their battery apart. The teacher pointed this out to the rest of the class as a possible reason why it had not worked but did not test the idea further. Unfortunately, because Ms. Beam never realized what the problems were, none of the batteries worked in any of her remaining classes for the rest of the day.

After the observations I did some troubleshooting of my own and realized the activity had not worked for two reasons. First, and most importantly, the blotter paper was never saturated and that was necessary for a current to flow within the circuit to facilitate the transfer of electrons. The second issue was that there was very little wire sticking out of the insulator on the ends of the small light bulbs. Stripping away more of the insulator would have ensured a better metal-to-metal connection with the tape. The fact that the lesson did not work for Ms. Beam indicated gaps in her PCK because she did not know the curriculum or understand all of the possible outcomes of the experiment or how to fix it if it did not work. Additionally, there was evidence of SMK gaps because Ms. Beam did not seem to realize that there could be no circuit without the electrons flowing through the saturated blotter paper. When asked about it in the interview she said she thought the fact the blotter paper was dry may have had something to do with why it did not work, but when asked directly if the electrons actually had to flow through the paper she answered “no.”

Observed Gap Indicators Related to Student Input

Much of the research involving teachers' learning from practice focuses on their interactions with students (Akerson, 2005; Akerson, Flick & Lederman, 2000; Da-Silva et al, 2007; Jones, Carter, & Rua, 1999; Seymour & Lehrer, 2006); the data from the present study support the findings of this research. As mentioned previously, within the category of student input in the classroom, events that indicated gaps in teachers' science content knowledge included student errors; student questions; student responses or ideas; inconsistencies in student data; and teachers dismissing plausible student ideas (See Table 4.3).

Student errors. Of the five observed instances (four teachers) in which student errors led to an indication of gaps in the teacher's knowledge, three indicated SMK gaps and all five indicated PCK gaps. The teachers, however, only recognized one of the SMK gaps and two of the PCK gaps. I observed three ways that student errors in the classroom indicated gaps in the teachers' science content knowledge: (a) when the teacher validated and/or repeated the student error; (b) when addressing the student error indicated a gap in the teacher's ability to adequately explain the concept; and (c) when the teacher was not anticipating the student error and therefore learned more about her students' thinking.

One instance in which a student's SMK error also indicated the teacher had similar SMK gaps occurred when Ms. Mepps asked a student to tell the class his answer for what would be the best method for separating aluminum and lead. The student said that magnetism would work and Ms. Mepps agreed that magnetism could be used, but then added that weight could be used as well. While Ms. Mepps's SMK gap was also related to errors on her answer key, the issue originally came to light because she both validated and repeated the student's SMK error in the classroom.

In another instance, a student error in the classroom illuminated a gap in Ms. Mepps's PCK. The student suggested that water was needed to separate things by weight. Ms. Mepps recognized that this was not a correct assumption and quickly searched for something she could use to demonstrate separation by weight without water. She grabbed the bottle with beads and salt (described previously) to try to demonstrate the concept, but that model did not adequately demonstrate the concept of separation by weight. In this instance Ms. Mepps seemed to understand the concept the student had misunderstood, but she was unable to quickly find an accurate model or explanation to demonstrate it.

In another class, Ms. Keller gained a better understanding of how her students were thinking because of an error that many of them made when they were labeling the charges of protons, neutrons and electrons. During the first observed class period, Ms. Keller simply told her students "N stands for neutral." In the last class of the day, however, she said "N stands for neutral, *not* negative." When questioned about the difference between what she said in the two classes, Ms. Keller explained that in her earlier classes when she asked her students to label the charges of protons, neutrons and electrons, many of her students said "neutrons are negative." She had not anticipated that they would make that error, so she made sure to emphasize that neutrons are neutral, not negative in her later classes. Because of her students' errors, she realized she had not anticipated this common misconception and that she had not previously represented the content in a way that would adequately address the misconception.

Student questions. Four of the teachers encountered gaps in their science content knowledge as a result of student questions. Of these 18 instances, 14 indicated SMK gaps and nine indicated PCK gaps. The teachers recognized their SMK gaps more than half the time and recognized their PCK gaps two thirds of the time. It is important to note that eleven of these instances came from the same teacher, Ms. Mepps.

One instance of the teacher not knowing the answer to a student's question took place when one of Ms. Mepps's students asked her about the temperature of the earth's inner core. She told her students that she did not know what it was and added that she did not think it was in their textbook so they did not have to worry about it. In another instance during another class, one of Ms. Mepps's students asked: "if you give blood to someone, do they have your DNA?" The teacher seemed to deflect the question when she responded, "they aren't going to become you." When questioned about it later she said "I really didn't know how to truly explain that… I don't know exactly how all that works… That is another one of those things I'd have to Google." In another example, one of Ms. Beam's students asked what would happen if they got the copper sulfate solution they were using on their skin. Ms. Beam somewhat deflected the question and simply said "don't stick your finger in it." If the teacher had read the safety warning on the bottle of copper sulfate powder, which said to flush the skin with water in case of contact, it seems reasonable that she would have answered the question differently by addressing the safety issues the student was asking about.

In another instance, previously mentioned above, Ms. Mepps responded to a student's question with an incorrect response. The student had asked if humidity was a mixture. Ms. Mepps responded, "It is a solution because air is dissolved in water." However, carbonated water, not humidity, is an example of air dissolved in water; humidity is a gaseous mixture of air and water. When questioned about her response during the interview Ms. Mepps explained that another teacher had previously given her the definition of humidity she shared with her class.

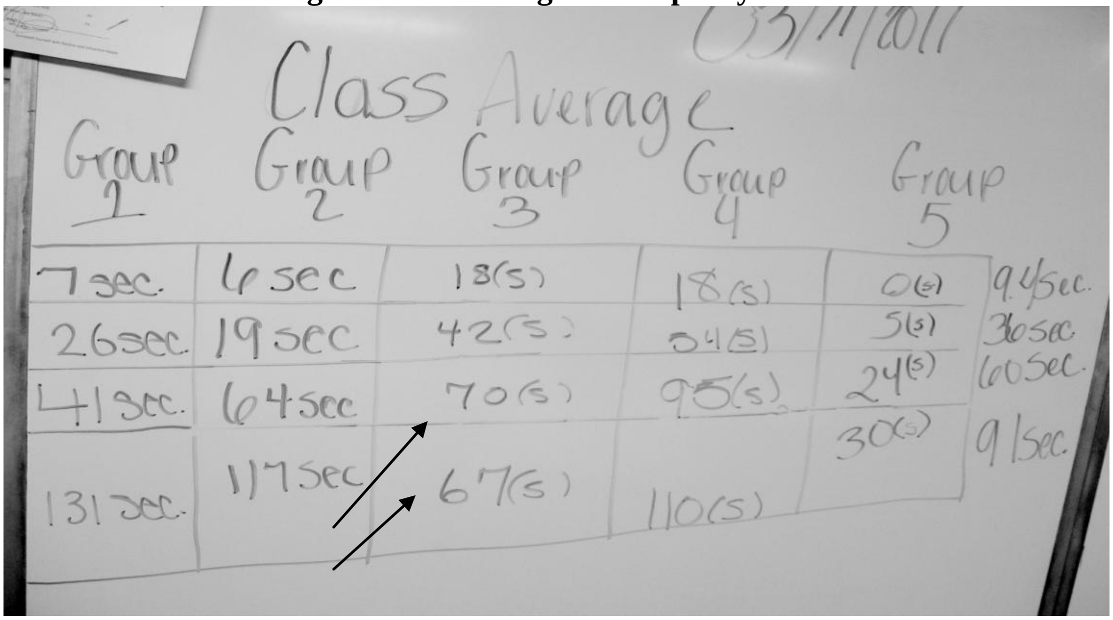
In one interesting example, one of Ms. Keller's students asked her why wind turbines can still turn when it is not windy. In response, the teacher explained that the higher up you go the windier it can be. Although this was an appropriate response, when questioned about it in the interview she explained that her response was her best guess and she was not sure if it was a correct response. From her response, it was clear that when the student asked the question it illuminated a gap in Ms. Keller's knowledge. Further, although she thought of a plausible and accurate response to the question, she still needed to double check her thinking to solidify her learning.

Student responses or ideas. All six of the teachers encountered gaps in their science content knowledge as a result of student responses or ideas. Of these 12 instances, six indicated SMK gaps and eight indicated PCK gaps; the teachers recognized most of these gaps. In one instance, Ms. Mepps was having difficulty coming up with an example of a mixture and one of her students said that chocolate milk was a mixture. She paused for a moment before validating the student's response. In the interview she explained that she paused because she was double-checking his answer in her mind. Although her initial pause indicated she did not have enough examples of mixtures on hand, the fact that she had to take the time to double check his answer in her mind was an indicator that she was not initially sure if chocolate milk was an adequate response. In another instance Ms. Keller paused the video in a new place during the second class I observed. The video showed pieces of chalk dissolving in two different solutions and she pointed out that one of the pieces of chalk was dissolving faster in the acidic solution. When questioned about it in the interview, Ms. Keller said that some of her students had noticed the difference so she started pointing it out in her later classes. Also, as mentioned earlier, one of Ms. Ardis's students suggested that rubbing the motor on a rubber band slowly and then quickly to see which would make the light attached to the motor light up better. The student suggestion took place in the first class, but Ms. Ardis was the one who suggested the idea to the groups of students doing that inquiry activity in the last class of the day. Essentially, the student's idea earlier in the day had changed the way the teacher thought about and taught the activity in later classes. In another example, one of Ms. Lane's students suggested that the esophagus was part of the respiratory system, which Ms. Lane said led her to rethink the model of the respiratory system she had in her mind.

Inconsistent student data. Recognizing inconsistencies in student data is among new teachers' content-related needs (Britton & Kinghorn, in preparation). Both observed instances of this phenomenon occurred during the second observation of Ms. Beam (who recognized her PCK gaps in both cases but did not recognize the SMK gap illuminated in one of the cases) when her students were doing an inquiry activity that involved charging batteries for set amounts of time to see how long the batteries would light a flashlight before running out of energy. The students were supposed to make sure their batteries were drained enough that they did not light up the flashlight and then measure the number of seconds the batteries did light the flashlight after being charged for 30, 60, 120 and 240 seconds respectively. The classroom chart of the different groups is shown in Figure 4.1. The purpose of the lesson was for the students to see evidence indicating that the longer the batteries were charged, the longer they would light the light.

The first inconsistency in student data was inconsistent data measurements between groups. This happened because groups were carrying out the procedure differently. For example, one group stopped their timer when the light dimmed instead of when it went out completely. Another group had the same person putting the batteries into the flashlight and turning on the timer so they lost a few seconds during each experimental condition. In neither case did the

Figure 4.1
Class Average Chart Showing a Discrepancy in Student Data



teacher did note the lack of uniformity in carrying out the activity procedures. Another group did not turn on their timer until the teacher specifically told them to and lost four to five seconds. Ms. Beam, however, did not point out the need to account for the loss of time in their recorded data. When asked about the discrepancies in student data between groups, Ms. Beam suggested the differences may have occurred because each battery may have had differing amounts of useable energy, but she did not seem to consider the fact that her students were carrying out the experiment in different ways. This seemed to be an unrecognized SMK error related to organization and the need for uniform methods for collecting and reporting data. Additionally, although she did not feel the need to correct their procedures, she did learn more about her students' thinking, which both illuminated and filled PCK gaps.

The other inconsistency in data was within one of the groups. As noted in Figure 4.1, Group 3 recorded that the light lit 70 seconds after the 120 second charge and 67 seconds after the 240 second charge. Ms. Beam did not initially seem to notice this discrepancy, but after a student pointed it out she addressed it with the class. She suggested it may have happened because the students picked up the wrong batteries, which was one plausible explanation. In the interview Ms. Beam explained it was an issue she had not anticipated and that she had had to come up with a plausible explanation on the spot. As a result of this event, Ms. Beam changed her instructions in the last class of the day and reminded students to make sure they picked up their own batteries from the chargers. In this instance, because she was not expecting the inconsistencies in the data, the gap was considered a PCK gap.

Dismiss plausible student ideas. Ms. Ardis and Ms. Beam both encountered gaps in their science content knowledge when they dismissed plausible student ideas. Because they did not recognize these student ideas as plausible or acceptable, and because they did not take the time to consider the student ideas as potentially valid, the teachers missed out on opportunities for their own learning. In all three instances the events indicated both SMK and PCK gaps, and all were unrecognized by the teacher. During one of Ms. Ardis's classes her students were having difficulty with an activity where they were supposed to rub a motor connected to a small light bulb on a rubber band stretched around a book. The students were having difficulty because the rubber bands kept breaking. One student realized that the sole of his shoe was rubber and decided to rub the motor on his shoe. The light lit up almost immediately. When he excitedly pointed it out to Ms. Ardis her response was "No, no, no! Don't do it on your shoe. It did work though. Is that rubber on your shoe? No, don't do it again!" By so quickly dismissing the creative idea a student had come up with, Ms. Ardis both potentially discouraged her student from coming up with future similar ideas and potentially limited the future learning opportunities for herself and her students.

In another example during the same observation, one of Ms. Ardis's students suggested that riding a skateboard up a ramp was an example of using an inclined plane to make work easier. That was not an example Ms. Ardis was looking for so she dismissed that idea and instead suggested that carrying boxes up a ramp as an example. As Ms. Ardis put it,

> I tried to explain to her that an inclined plane was going to be level and you needed to lift [it] up at some level. I wanted her to understand that a skateboard ramp was a U shape and technically you're not pulling anything or pushing anything up and down that ramp.

Ms. Ardis did not seem to realize that a skateboard ramp could be an inclined plane and the individual on the skateboard is the object being moved (work). It was unclear whether the student had been referring to a straight skateboard ramp (an inclined plane) or a half-pipe type ramp as Ms. Ardis assumed. Yet regardless of the ramp type, Ms. Ardis was incorrect in her assumption that no work was being done in the student's example. Had she asked her student to further explain her answer, rather than dismissing it, Ms. Ardis could have increased her own knowledge as well as potentially validating her student's response.

The other observed example of dismissing a student idea was a bit more nuanced. As mentioned in the section on unexpected lesson outcomes, when the copper and zinc battery experiment did not work in Ms. Beam's class, one of her students correctly suggested that the problem may have occurred because the blotter paper had not been saturated between the two pieces of metal. In this case, Ms. Beam highlighted the student idea to the entire class and asked all of the groups check their blotter paper. They all discovered that it was dry between the metal pieces. Unfortunately, that was as far as Ms. Beam's encouragement of the idea went. She encouraged her students to come up with good ideas and praised this particular idea as insightful; however, she ultimately dismissed the idea in favor of her own explanations for why the experiment may not have worked (incorrectly mixed copper sulfate solution or bad wire connections). Consequently, she never tested the student idea, and none of the batteries worked in the last class observed that day either. During the follow-up interview, Ms. Beam said that she did not think that the paper needed to be saturated with the solution between the pieces of metal for the circuit to be complete. In this case she recognized that she did not know why the experiment did not work but she did not seem to recognize that the information given by her student was the solution to her problem.

Typology Summary

As noted previously, multiple events in the classroom often indicated the same gaps. For example, Ms. Mepps's student asked how to separate different substances by weight and she reached for a bottle containing salt and different sized beads to demonstrate separation by weight only to discover that shaking the bottle separated them by size instead. The student question, Ms. Mepps's need for an alternate representation for the concept, and the unexpected outcome of the model all indicated the same PCK gaps. Yet, although each of these events was connected to the others and worked in tandem as gap indicators, it was still important to separately describe each one. The typology above provides evidence of these varied potential gap indicators that an outside observer (or a teacher reflecting on her own practice) can use to better identify potential gaps in a teacher's science content knowledge that are encountered during classroom instruction.

The data also provide evidence of whether or not teachers recognized the gaps in their science content knowledge, but in most instances the typology does not provide clear evidence as to why teachers may have recognized some gaps but not others. Additionally many of the different types of gap indicators only function to identify potential gaps, but would not be considered triggers for learning (e.g. teacher looking up information in class). The next section addresses types of potential gap indicators that seemed more likely to also involve the teacher recognizing a gap as well as indicators that seemed less likely to involve the teacher recognizing a gap.

Recognizing Gaps

It was usually clear from the data whether teachers recognized the science content knowledge gaps they encountered during the observations, but the reasons why they recognized or failed to recognize these gaps were much more difficult to ascertain. This difficulty arose in part because the interview questions were not designed to elicit information about what the teachers were doing and thinking when they encountered gaps. Additional probing questions would have been necessary to tap into the complex metacognitive processes in play as a teacher accessed her current knowledge, determined if the potentially new information fit her current schemas for and conceptions of the content, and determined what to do about it. Additionally, many of the types of potential gap indicators in Table 4.3 clearly highlighted and illuminated the presence of gaps but were the product of—not necessarily the origin or cause of—a teacher recognizing a gap.

For example, the three teachers who looked up information in class all recognized all of the gaps that this classroom behavior indicated. Indeed, the very behavior of looking up additional information in class provided evidence that the teacher was attempting to bridge gap(s) she had already encountered and recognized. It does not, however, indicate what triggered the recognition of the gap in the first place. An interview question such as “why did you choose to look up that information in class?” followed by a response such as “I realized I did not know the material as well as I should have” only indicates that the teacher knew there was a gap in her knowledge. It does not adequately tap into the metacognitive thought processes that led her to encounter and recognize that gap in her knowledge. Similar situations when the gap indicator was not necessarily the learning trigger included when teachers: made changes in their lesson plans; realized they needed an alternate explanation or representation for a concept in class; experienced aha moments in the classroom; and encountered unexpected lesson outcomes. In these cases the teachers recognized all but three of the 43 gaps these classroom events indicated. Still, although these classroom events clearly indicated gaps and the teachers' interview responses clearly indicated they recognized those gaps, it was often unclear what initially led the teacher to encounter the gap or why the teacher recognized the gap.

In other cases, such as when the teachers presented incongruent content in the classroom and when teachers dismissed plausible student ideas, the teachers did not recognize any of the 7 encountered gaps. The teachers also recognized 50% or less of the gaps related to the errors they made in class or the interview and the gaps related to student errors in the classroom. In these cases there is an inherent challenge in recognizing gaps because we cannot expect teachers to know when they do not know something. For example, when Ms. Mepps stated that humidity was air dissolved in water (more consistent with the definition of carbonation) she thought she was right. Without the presence of a mentor teacher or student who already knew the concept and could point out her misconception, there was a necessarily low expectation that she would have known by herself that she had made a mistake or misunderstood/misrepresented the concept.

For the remainder of the types of gap indicators, the teachers recognized some of their gaps and did not recognize others. It seems evident that in many cases it was not necessarily the nature of the gap indicator or even the potential learning trigger that most influenced whether the teachers recognized their gaps, but rather how the teachers were accessing their current content knowledge in the context of potentially new information in class. In some instances, the teachers' interview responses started to hint at the metacognitive processes they went through as they had encountered and recognized the gaps in their knowledge. For example, when Ms. Mepps was having difficulty coming up with an example of a mixture, one of her students suggested that chocolate milk was a mixture. The teacher paused for a moment before validating the student's response. In the interview she explained that she had paused because she was "double-checking" his answer in her mind. Although this example lacks the necessary detail to fully understand the process Ms. Mepps went through as she encountered and recognized a gap in her knowledge (not knowing immediately that chocolate milk is an example of a mixture), this interview response did hint at her metacognitive process of comparing what the student said to her working definition of a mixture.

Overall the data did not include enough of—or an adequate depth of—this type of information to sufficiently determine any clear patterns explaining why teachers recognized some knowledge gaps and did not recognize others. Although it is unclear from the data what specific types of situations may lend themselves to allowing the teacher to better recognize gaps in her science content knowledge, Chapter 6 addresses teacher classroom practices that may generally help teachers better recognize the gaps in their science content knowledge through helping them to more reflectively approach their teaching practice.

Summary

A number of types of classroom events resulted in multiple teachers encountering gaps in their science SMK and/or PCK. Although the data do not conclusively suggest which types of classroom events are more likely to illuminate gaps or which of these events are more likely to facilitate teachers' recognition of the gaps they encounter, it was clear that certain types of events caused multiple teachers to encounter gaps in their science content knowledge, whether they recognized the gaps or not. It is also important to point out that these frequencies are only instances that I observed and identified as indicators of actual gaps in the teachers' science content knowledge. It is also possible there were other gaps that the teacher experienced that were not visible or apparent to an outside observer and that the teacher either did not recognize or did not think to share in the interview. In a very real sense, the instances listed in Table 4.3 are only a snapshot of these teachers' experiences in the classroom during two different days of instruction. These data cannot and are not intended to be comprehensive in nature.

Consequently, rather than providing a detailed analysis of the possible causes and effects of the events provided in Table 4.3, this section of the results simply described the observed events in the context of both observations and the follow up interviews and provides a picture of how these events occurred for individual teachers in this study. Understanding the nature of these events in the context of the cases presented here may help other teaching practitioners and teacher educators know what types of classroom events to look for as potential opportunities for learning through reflective practice. The goal of this chapter was to provide observation-based evidence of these gap indicators (including relevant triggering events) along with their frequencies, the frequencies and general types of gaps encountered, and how many of these gaps the teachers recognized independently. The remaining two results chapters examine possible reasons teachers encountered gaps in their own science content knowledge and what classroom practices may have influenced whether they recognized the gaps.

CHAPTER 5

RELATIONSHIPS BETWEEN TEACHERS' PREVIOUS KNOWLEDGE AND THEIR OBSERVED CONTENT GAPS

Chapter 4 focused on the types of classroom events and behaviors that indicated gaps in teachers' science content knowledge, as well as information about whether teachers recognized these gaps in their knowledge. This chapter will address the third research subquestion—how does the depth and nature of teachers' knowledge affect their content knowledge gaps—by examining relationships between aspects of the teachers' prior content knowledge and the observed science content knowledge gaps addressed in Chapter 4. The first examination of teachers' prior content knowledge focuses on their undergraduate science coursework. A second possible indicator of teachers' content knowledge is their confidence in their knowledge of the concepts they are teaching (Britton & Kinghorn, in preparation). Consequently the chapter then addresses the possible relationships between the observed gaps for each visit and each teacher's stated levels of confidence with regard to the science content she was teaching during those observations. Another factor that seemed to affect the number of gaps each teacher encountered was her level of daily preparation for each individual day of instruction, so that is also addressed in this chapter.

Teachers' Post-Secondary Science Preparation

When this research was proposed, the intent of the second research question was to select some participants with elementary certifications and some with secondary certifications to see whether there were relationships between subject matter preparation and knowledge gaps encountered by teachers. The hypothesis was that elementary-certified teachers with relatively less post-secondary science coursework might encounter more gaps during instruction than did secondary-certified teachers who had taken relatively more post-secondary coursework. The teachers in this study, however, all held traditional or emergency secondary credentials so a comparison between elementary and secondary preparation was not possible.

Instead, I examined post-secondary science coursework taken by the teachers. During the first interviews each teacher provided a verbal list of the post-secondary coursework she had completed. Table 5.1 shows the number of courses each teacher completed in different science areas. All the teachers completed core post-secondary courses in biology and chemistry; five of the six took at least one college physics course. Additionally, two teachers took geology courses. All of the teachers had considerable preservice preparation in the life sciences. Because all of the teachers had traditional or emergency secondary certifications and had all taken multiple different science courses across the disciplines, there was insufficient variation in the teachers' science coursework to contrast between teachers who seemed more or less prepared to teach middle-school science in general.

Table 5.1
Post-Secondary Courses Taken in General Science Content Areas

Teacher	General Biology	Anatomy/ Physiology	Biology (Other)	General Chemistry	Chemistry (Other)	Geology/ Earth Science	General Physics	Physical Science (Other)
Lane	1	1	1	1	1	0	1	0
Ardis	1	1	7	1	1	0	1	0
Kidd	1	1	3	1	0	0	1	2
Keller	1	0	4	1	0	4	1	1
Beam	1	1	1	1	0	0	0	0
Mepps	1	1	1	1	0	1	1	1

Note: Each # indicates that the teacher completed a course in that subject area but does not account for the fact that some courses may have spanned multiple semesters (e.g. Anatomy & Physiology).

Another way that post-secondary coursework can influence teachers' preparedness to teach is the degree of alignment between their post-secondary science preparation and the subjects they teach. In other words, if a teacher is teaching a subject for which she did not complete a college course, her content related needs for effectively teaching that subject increase (see Kinghorn & Britton, in preparation). Table 5.1 reveals a potential alignment issue for one of the teachers. Ms. Beam was teaching an eighth-grade physical science course (see Table 3.1), but had not taken any post-secondary physics courses (see Table 5.1). This misalignment between her preservice preparation and what she was required to teach is one possible explanation for why she encountered so many (33 total) observed gaps in her science content knowledge (see Table 5.2). When asked how she felt the science she took in college helped her teach physical science, Ms. Beam said that she would have felt more comfortable teaching life science than physical science. She also said she felt she had been prepared to teach the chemistry-related aspects but not the physics-related aspects of the physical science course she was teaching. Table 5.2 also shows that Ms. Beam was among the top three teachers in the number of gaps she encountered during her observations and was also among the bottom three teachers in the

Table 5.2
Frequencies of Observed SMK and PCK Gaps

Teacher/ Visit	SMK Gaps	Recognized (%)	PCK Gaps	Recognized (%)	Total Gaps
1Lane/1	0	NA	1	1 (100%)	1
Lane/2	3	3 (100%)	4	4 (100%)	7
Ardis/1	2	1 (50%)	4	3 (75%)	6
Ardis/2	10	6 (60%)	16	13 (81%)	26
Kidd/1	0	NA	2	2 (100%)	2
Kidd/2	0	NA	5	5 (100%)	5
Keller/1	7	6 (86%)	9	9 (100%)	16
Keller/2	2	1 (50%)	5	3 (60%)	7
Beam/1	9	5 (56%)	12	9 (75%)	21
Beam/2	3	2 (67%)	9	9 (100%)	12
Mepps/1	15	9 (60%)	13	9 (69%)	28
Mepps/2	1	1 (100%)	2	2 (100%)	3

The information in this table was taken from Table 4.2

percentages of those gaps that she recognized. Although there are other possible explanations for these data that will be addressed later, the misalignment of Ms. Beam's preservice preparation and the subject she was teaching is something that must not be overlooked as a possible factor in her knowledge gaps.

Influences of Teachers' Confidence in Their Knowledge of the Science Content

Another potential indicator of a teacher's prior science content knowledge and preparation is her confidence in her knowledge of the subject she is teaching. Although post-secondary coursework can provide a general idea of what concepts a teacher may have been exposed to in her preservice preparation, a teacher's expressed level of confidence in her knowledge of the subject is a possible indicator of how well she thinks she actually knows the concepts she was introduced to in college.

Near the beginning of each follow-up interview I asked the teacher how confident she was about the science content and concepts she had taught that day. Each teacher's level of confidence was determined from her responses to two interview questions: "How well did your preservice teacher preparation prepare you for the subject you were teaching today?" and "How confident were you in your knowledge of the subjects you were teaching today?" Based on these answers, I rated confidence levels as *high*, *moderately high*, *moderately low*, or *low*. These ratings are listed in Table 5.3, along with the gaps information from Table 5.2 so that the frequencies of gaps can be directly compared to each teacher's expressed level of confidence. It is important to note that these ratings compare the level of confidence between visits for each individual teacher, not between teachers. In other words, the information in Table 5.3 does not indicate that Ms. Lane expressed greater confidence than Ms. Mepps, but that Ms. Mepps expressed greater confidence for Visit 2 than Visit 1. The data in Table 5.3 suggest that teacher confidence affected the number of gaps a teacher encountered in two situations: (a) when the teacher had high confidence for both lessons; and (b) when the teacher had higher level of expressed confidence for one visit than the other.

Table 5.3
Frequencies of SMK and PCK Gaps During Observations and Expressed Confidence in the Science Subject Taught

Teacher/ Visit	SMK Gaps	Recognized (%)	PCK Gaps	Recognized (%)	Total Gaps	Confidence in Knowledge*
Lane/1	0	NA	1	1 (100%)	1	High
Lane/2	3	3 (100%)	4	4 (100%)	7	High
Ardis/1	2	1 (50%)	4	3 (75%)	6	High
Ardis/2	10	6 (60%)	16	13 (81%)	26	High
Kidd/1	0	NA	2	2 (100%)	2	High
Kidd/2	0	NA	5	5 (100%)	5	High
Keller/1	7	6 (86%)	9	9 (100%)	16	Low
Keller/2	2	1 (50%)	5	3 (60%)	7	High
Beam/1	9	5 (56%)	12	9 (75%)	21	Moderately High
Beam/2	3	2 (67%)	9	9 (100%)	12	High
Mepps/1	15	9 (60%)	13	9 (69%)	28	Low
Mepps/2	1	1 (100%)	2	2 (100%)	3	High

*The relative confidence in knowledge comparisons are based on teacher responses and are comparisons within teachers, not between teachers.

High Confidence Level for Both Visits

Three teachers—Ms. Lane, Ms. Ardis, and Ms. Kidd—expressed high levels of confidence during both visits. For two of these teachers, Ms. Kidd and Ms. Lane, their high expressed levels of confidence in the subject knowledge they were teaching seemed directly related to the numbers of gaps they encountered during each visit.

In the follow-up interviews Ms. Kidd specifically said that she was “very confident” about her knowledge of the science content she had been observed teaching. She had taken enough science classes in college to be one class shy of a pre-medicine degree, and she expressed that this science background made her “far more of an expert that a lot of the other science teachers [her students] are going to have.” Ms. Kidd also explained that she liked it when her students asked tough questions because she could then share answers based on what she did in her college classes. Further, she felt comfortable enough with the subject matter that she did not have to prepare nearly as much as she would if she were teaching something she did not know as well. As she put it, this added confidence allowed her to “think on [her] feet more” and be able to make changes in the middle of a lesson if necessary. During my two visits with Ms. Kidd I did not observe her encounter any SMK gaps, and observed her encounter only seven PCK gaps, all of which she recognized.

Ms. Lane also expressed high levels of confidence in her knowledge of the observed lessons during both visits. During both observations, Ms. Lane encountered a total of three SMK gaps and five PCK gaps, all of which she recognized. Additionally, most of the events Ms. Lane and Ms. Kidd spoke of in interviews had to do with PCK gaps and focused mainly on understanding how their students were thinking about different concepts.

Ms. Ardis also expressed high levels of confidence during both visits, but encountered more gaps during her second observation than during her first observation. Although this does not fit the pattern of the other two teachers who expressed high levels of confidence during both visits, differences in the extent to which Ms. Ardis’s prepared for class on those days may explain the discrepancies in the number of gaps she encountered from one visit to another, an issue that will be addressed later in this chapter.

Differing Levels of Confidence across Visits

In contrast to the teachers above, three teachers—Ms. Keller, Ms. Mepps, and Ms. Beam—were more confident teaching the subject matter during one visit than the other. This discrepancy in their levels of confidence seemed related to the number of gaps each teacher encountered during instruction on these days.

For example, Ms. Keller encountered more gaps when she was teaching about different types of energy (seven SMK and nine PCK gaps) than when she taught about the parts of an atom (two SMK and five PCK gaps). She did, however, recognize nearly all of the gaps during both visits. In the case of the first visit, Ms. Keller clearly stated that she was less confident in her knowledge of the material she was teaching, so it was not surprising that she encountered more gaps in her knowledge during this lesson. While discussing her lack of confidence, she said, “Typically I find myself relying on the textbook when I don’t know a topic as well.” She explained that for genetics, a subject she felt very comfortable teaching, she had used the book mainly as a reference because she felt comfortable pulling resources from other places. When she was teaching about energy during the first observation, however, she said that as she watched a video about different types of energy with her students and then went over the PowerPoint presentation of the notes, she realized that she did not know the information as well as she needed to know it. Consequently, in her later classes she just had students watch the video and did not do the PowerPoint presentation because she realized she needed to spend more time studying the topic to teach it well.

Similarly, Ms. Mepps encountered 15 SMK and 13 PCK gaps when teaching about mixtures, compounds, and solutions during her first visit, but encountered only one SMK gap and two PCK gaps during her second visit when teaching about the layers of the earth. When asked about teaching earth science she said: “This… unit [earth science] always makes me feel so much more confident as a teacher because this is my strong suit. I’ve always loved earth science and fossils and rocks. I seriously thought about being a geologist… [and] I know I can back up what I’m saying because this is my area [of interest].”

When Ms. Mepps was teaching about mixtures, compounds, and solutions, she was less confident in her own knowledge and relied heavily on the answer key she had, which had some incorrect answers on it. This was not the original key, but a key provided to her by a more experienced teacher in the school. When questioned about how confident she was with the answers the more experienced teacher had given her, Ms. Mepps said, "I felt better because some of them were correct… but some of them I thought were too confusing for the kids to use so I never counted those against them." Brass was one of the items on the worksheet, but during the interview Ms. Mepps said she thought brass was some metal "mixed in with mercury maybe." She continued, "I don't even know the composition of brass. That is why I couldn't verify that or not." Throughout the interview she explained that she was unsure of her own knowledge, so she relied heavily on the answers she had been given on her answer key, even when they contradicted what she originally thought the correct answers should be.

These examples from Ms. Keller and Ms. Mepps support the idea that teachers can be well equipped (with regard to their content knowledge) to teach some subjects or concepts while simultaneously lacking knowledge of other subjects and concepts and being less equipped to teach in those areas.

The other example of differing confidence levels from a teacher is more complicated. Ms. Beam also expressed different confidence for her two visits—moderately high confidence for the first observation and high confidence for the second. As expected, she encountered few gaps during the lesson about which she was more confident. There was, however, another important variable, her preparation for class, which appeared to have a greater influence on the gaps she encountered.

Relationships among Daily Preparation to Teach, Confidence, and Gaps

As noted above, confidence in knowledge alone did not seem to explain the differences in the numbers of gaps between visits for Ms. Beam and Ms. Ardis. Each of these teachers expressed high or moderately high confidence during both visits, but also encountered many more gaps during one visit than the other. In both cases, their level of daily preparation for the lesson seemed to be a more accurate indicator of the reasons for these discrepancies in the numbers of gaps encountered from one visit to another. When it became apparent that confidence alone was not adequate to explain why these two teachers may have encountered more gaps during one visit than another, I further analyzed the data on teachers' preparation to teach the observed lessons. Because teachers' daily preparation to teach was not an initial focus of the research, however, the data collected about teacher preparation were limited. Consequently, I can only address instances in which it seemed clear that a teacher's confidence and/or encountered gaps may have been influenced by that teacher's level of daily preparation to teach the observed lessons.

Although the current study did not focus on the knowledge gaps teachers encountered while preparing to teach, the topic of daily preparation to teach was addressed in both the observations and the interviews. Unlike expressed confidence levels, which relied solely on the teachers' self reports, the degree of a teacher's preparation was determined using both their responses to questions about what they had done to prepare for the lesson that day and observations of their teaching. I rated each teacher's level of preparation on a scale of *high*, *moderate*, and *low*. These ratings were based on both the amount of time the teacher reported preparing and the adequacy of the preparation. For example, if a teacher said she had spent considerable time preparing for or rehearsing the lesson and she seemed prepared to teach during the observation, she received a high rating. A high rating was also assigned if the teacher seemed prepared for class and expressed that she previously had adequate knowledge of the subject and only needed relatively little time to prepare or rehearse it. In contrast, low ratings were given when it appeared from the observation that the teacher had not read through or rehearsed a lesson or tested/prepped an experiment or inquiry activity prior to class. Teachers were given a moderate rating when it was clear they had engaged in some preparation or rehearsal before class, but when that preparation was not adequate to effectively teach the lesson.

With regard to science content knowledge gaps, the current study only addresses the observed gaps that teachers encountered in the classroom. The extent and adequacy of teachers' preparation to teach, however, was a potentially influencing factor in the number of gaps each teacher encountered during the classroom observations. For example, a teacher could have started preparing a lesson with limited prior knowledge and encountered many gaps while preparing to teach. Consequently, even though the teacher's previous background knowledge may have been limited, the gaps encountered while preparing to teach would less likely be encountered during actual instruction. In contrast, if a teacher had not adequately prepared for a lesson, the gaps that may have been encountered during prior preparation would more likely have been encountered during on-the-spot preparation during instruction.

Table 5.4 adds teacher preparation for class to the information contained in Table 5.3. Displaying all of this information together helps to reveal possible interrelationships among teachers' preparation, expressed confidence, and observed science content knowledge gaps encountered during instruction. Although a teacher's expressed levels of confidence in her knowledge were related to the number of gaps she encountered during the observed lessons, confidence alone did not seem to explain why some of the teachers encountered more or less gaps than other teachers or why they may have encountered more or less gaps between their two observations.

Table 5.4
Frequencies of SMK and PCK Gaps and Relative Confidence / Preparation from Observations

Teacher/ Visit	SMK Gaps	Recognized/ %	PCK Gaps	Recognized/ %	Total Gaps	Confidence in Knowledge*	Preparation for Lesson
Lane/1	0	NA	1	1 (100%)	1	High	High
Lane/2	3	3 (100%)	4	4 (100%)	7	High	High
Ardis/1	2	1 (50%)	4	3 (75%)	6	High	High
Ardis/2	10	6 (60%)	16	13 (81%)	26	High	Moderate
Kidd/1	0	NA	2	2 (100%)	2	High	High
Kidd/2	0	NA	5	5 (100%)	5	High	High
Keller/1	7	6 (86%)	9	9 (100%)	16	Low	Moderate
Keller/2	2	1 (50%)	5	3 (60%)	7	High	High
Beam/1	9	5 (56%)	12	9 (75%)	21	Moderately High	Low
Beam/2	3	2 (67%)	9	9 (100%)	12	High	Moderate
Mepps/1	15	9 (60%)	13	9 (69%)	28	Low	Moderate
Mepps/2	1	1 (100%)	2	2 (100%)	3	High	High

*The relative confidence in knowledge comparisons are within, not between, teachers.

The additional analysis of daily preparation was conducted specifically to address the discrepancies in gaps between visits for Ms. Beam and Ms. Ardis. Ms. Ardis expressed equally high levels of confidence in her knowledge of the content she was teaching during both visits, but she encountered more than four times more gaps during her second visit than her first visit. Additionally, although the fact that Ms. Beam expressed slightly less confidence during her first visit than her second one, her level of preparation for class each day seemed to be a more important contributing factor into why she encountered nearly twice as many gaps in her first visit than her second one. The interrelatedness of high confidence and lower preparation in relation to gaps will be discussed below. Additionally, some teachers' interview responses suggested other possible patterns among confidence, preparedness, and gaps. These additional patterns will also be discussed briefly, along with their implications for potential future research.

High Confidence, Less Preparation, and Gaps

As noted above, during Ms. Addis's Visit 2 and Ms. Beam's Visit 1 both teachers expressed relatively high levels of confidence in their knowledge, which was similar to their confidence on the other visits. However, Ms. Ardis encountered 26 gaps during instruction in Visit 2 and six gaps during instruction in Visit 1. Similarly, Ms. Beam encountered 21 gaps during Visit 1 and 12 gaps during Visit 2. Confidence somewhat explained the discrepancy for Ms. Beam but could not account for the discrepancy for Ms. Ardis. Their levels of preparedness to teach each lesson did seem to be a large influencing factor in the number of gaps they encountered.

From my observations, I inferred that neither teacher had spent the time needed to be able to troubleshoot the inquiry activities they conducted on the days they encountered more gaps. Interestingly, both teachers reported attending professional development workshops where they engaged in the inquiry activities they were doing with their students. When they expressed high confidence, they both referred to the professional development workshops as a reason for that confidence. As Ms. Ardis put it, "Luckily with this stuff we had the training and I was pretty much prepared and we experienced the same things the kids experienced… so it made me more confident." Ms. Beam said she was fairly confident in her knowledge of the science content of the battery lesson she taught because she had attended the professional development workshop. She did, however, suggest that the set-up of the battery was something she needed to "look up better." She then explained that because she had experienced the lesson in the professional development workshop she prepared less. As she put it:

> I guess maybe personally I should have completed it on my own so I would have known the small things, like the minor things to expect when I was doing it on my own in the

> classroom myself as opposed to me and other peers where we kind of helped each other and… worked through the activity, and saw what was working and what was not working.

Both Ms. Beam and Ms. Ardis said they had not prepared adequately for class, which was also clear from the observations of their teaching. Ms. Ardis had read the lesson, gone through the inventory with her students and set up each station, but had not taken the time to test each activity before class. Ms. Beam did not spend any time preparing before class to set up and test the inquiry activity she did with her students, instead doing her initial preparation at the beginning of her first class. Not coincidentally, the teachers' lack of preparation seemed to trump their confidence, which is a possible explanation for the discrepancies in the numbers of gaps they encountered between each of their visits (see Table 5.4). In both cases the teachers encountered PCK gaps related to the set up of the curriculum, but they each also encountered SMK gaps that were related to fundamental principles upon which the inquiry activities were designed.

Ms. Ardis. During her first lesson, Ms. Ardis had adequately high preparation and high confidence in the content she was teaching and encountered a low number of gaps in her science content knowledge during the observed instruction. As she put it, "I didn't have to read a lot and copy down a lot and write down a lot this time. I read it, and it is all up here [pointing to head]. This is one of those things where I can just get up and go." During her second observation, however, she was only moderately prepared for what she had to teach. She took time to read the background information in the book so she could "remember exactly what we were doing and what might happen." Additionally, she took time to go through the boxes of supplies and do an inventory with her class, and she set up each station before class. She did not, however, test the different activities before class, and she encountered a number of troubleshooting issues during class as a result. For example, when she was trying to help one group of students balance a lever and it was not working, she did not realize that the apparatus had been constructed incorrectly in such a way that there was no possible way to get it to balance using the materials provided.

Because Ms. Ardis expressed similarly high levels of confidence during each observation but exhibited differing levels of preparation between the two observations, the discrepancy in her level of preparation is a probable explanation for why she encountered more than four times more gaps during her second observation (26 total gaps when she was only moderately prepared) than during her first observation (six gaps when she was highly prepared).

Ms. Beam. Ms. Beam's first observed class involved an inquiry activity in which her students made batteries out of copper and zinc metals submerged in a copper sulfate solution. From the observation it was clear that she had not prepared much before coming to class. She spent the first few minutes of her first class silently reading through the lesson before engaging with her students. When asked about it during the interview she said she was "getting to that type of prep information and reading the background information about the battery." Then she had to break an unopened seal on the copper sulfate powder to make the copper sulfate solution. She was unsure how much powder to put in the solution and did not measure it. She also told her students they needed to use alligator clips for the activity but later realized that they were not necessary so she told her students to put them back. Additionally, she was surprised when the zinc metal turned black (oxidized) immediately after it was placed into the solution. She was also surprised when none of the batteries worked, and she was unable to successfully troubleshoot the activity to figure out what was going wrong in any of her classes. Consequently, none of the batteries worked in the two observed classes.

Although Ms. Beam expressed moderately high confidence in her knowledge of the subject matter she taught during the first observation, her insufficient prior preparation to teach that lesson also potentially influenced the number of gaps she encountered. Consequently, it seems that lower confidence and less preparation were both influencing factors in why she encountered more gaps (21) during her first observation than during her second observation (12 gaps).

Additional Patterns among Confidence, Preparation, and Gaps

Confidence and preparation were relatively loosely operationalized in this study, and the decisions on how and to what extent to use them in the data analysis were unexpected to some degree and were developed as a result of initial data analyses. Still, because this is an exploratory study it is important to address some of the additional less supported potential relationships among confidence, preparation, and gaps that were present in the data even though the analysis of the data was notably more subjective in nature. Clearly, the data are limited, but the potential relationships discussed below certainly led to additional questions that will be addressed as candidates for potential future research in Chapter 7.

Expressed confidence in knowledge and daily preparation to teach seemed to be interacting variables, and the degree of preparation for class seemed to also have a direct impact on the number of gaps a teacher encountered during the observed instructional activities. As noted above, even when teachers expressed relatively high confidence in the subject matter for both the observed classes, teachers encountered more gaps on days when they were relatively less prepared for that day's instructional activities.

Additionally, high levels of preparation for a lesson may have boosted a teacher's confidence in her knowledge of the subject matter for that lesson. Further, a teacher's expressed low confidence could also have been influenced by inadequate preparation for that day's instructional activities.

High confidence, high preparation. Ms. Lane and Ms. Kidd expressed high levels of confidence, were highly prepared to teach, and encountered few gaps during observed instruction. In some ways, the high levels of confidence each teacher expressed may have been positively influenced by the adequacy of their prior preparation to teach that day.

As mentioned earlier, it seemed that Ms. Kidd's confidence came mainly from her preservice preparation, and being highly prepared for class on the observation days did not require much time or effort on her part. Ms. Lane, however, explained that she spent a lot of time preparing for her classes so that she would be able to know the content well. As she put it,

> "I teach [the lesson] to myself first... I try to make sure that I'm prepared because I feel like their goal is to catch me not knowing something even more than it is to learn. So I try to do my job and stay on top of what I need to know so that they can get what they need to know."

It seems reasonable that her extensive preparation for the observed classes may have contributed to the fact that she encountered only three SMK gaps and five PCK gaps during the two times she was observed teaching. In her case it seemed like her level of confidence may have been positively influenced because she taught the lesson to herself first.

Additionally, although it did not seem to be a contributing factor in the observed lessons, Ms. Kidd talked about times when she had not fully understood the concepts she was preparing to teach. In these instances she said she spent additional time preparing by finding other labs and doing research on her own "to kind of make up for some of that." She further explained that she made many connections between concepts as she prepared to teach because she "had to write an example of what [her answer] might look like to show [her students].” She also expressed that when her confidence level was high and she had adequately prepared she felt more comfortable making on-the-spot adjustments to instruction to better fit the needs of her students. She also stated that at times when she was less confident or comfortable with a lab or demonstration or when she had never seen it before she took extra time to go through the procedures and make sure it worked before she tried it in class.

Low confidence, moderate preparation. Ms. Lane’s desire to make sure she knew what she was teaching influenced her daily preparation for the observed lessons and may have positively influenced her confidence in that knowledge. Ms. Keller, however, seemed to experience the opposite. As mentioned above, the number of gaps Ms. Keller encountered during each visit was probably influenced by her expressed levels of confidence. Her level of confidence, however, also seemed to have been influenced by her level of preparation for each observed day of instruction. As noted above, as Ms. Keller encountered the discrepancies between the types of energy listed in the class video and the types of energy from the book that were in her PowerPoint presentation, she realized her knowledge of the concepts was not where it needed to be and that, even though she had read through the chapter and made the PowerPoint presentation, she had not adequately prepared to teach that portion of the class that day. As she put it,

> this current unit that I’m in I still have to go back and review. I’ve read the chapter and this is one I’m going to have to go back and look up more information on it… Energy and the periodic table are two that I’m going to have to review a lot.

She then added that she had prepared the PowerPoint presentation so students could take notes on it

> just in case of whatever, but I don't think I was ready to go over them… The [PowerPoint presentation] notes… were kind of an "if they get done with the video" rather than "this is a part of this lesson." I guess if that makes sense. Again I think it goes back to the comfort level. I have to go back and look this stuff up myself. I have to go back and reexamine what exactly I know… To be completely honest, I'm still not 100% sure what specifically we're going to cover in this unit. Like how in-depth we go with this. So, while the notes are based on the book and all the notes are what I think are the important things to take from the chapter, I think just conceptually, maybe to be able to explain it, I need to go back and review.

Ms. Keller had clearly taken time to put the PowerPoint presentation together, but she also said she was unsure if she would actually get to it that day. When she started going through it in her first class, it became apparent that she needed to prepare for and review the topic more extensively before she would be confident teaching it to her other classes.

Although additional research into how daily preparation and relative expressed confidence would be necessary to make any definitive judgment, it would not be surprising if Ms. Keller's expressed lack of confidence in the content she was teaching was influenced by the number of gaps she had encountered during instruction and the fact that she had realized her prior preparation was not sufficient to teach the lesson adequately.

Summary

Although the original intent of the second research question was to compare teachers who had clearly taken more or less post-secondary science coursework, this chapter has addressed the question with teachers who had all taken many post-secondary science courses. First, as noted in Kinghorn and Britton (in preparation), when there is a misalignment between the teacher's post-secondary coursework and what she is teaching, she may encounter more gaps during instruction.

Additionally, teachers' expressed confidence seemed to be an indicator of their content preparation because each teacher's level of confidence for each visit appeared to influence the number of gaps she encountered during instruction. When teachers were highly confident in the subject matter there was a trend toward relatively fewer gaps, and when they expressed lower levels of confidence in their knowledge of the subject matter there was a trend toward relatively more gaps. These gap trends, however, were also influenced by the adequacy of the teachers' preparation to teach each of the observed lessons. In some cases the differences in expressed confidence seemed to be the most influential factor in the number of gaps encountered. In other cases the level of preparation seemed to be the most influential factor in the number of gaps encountered. And in some cases the level of preparation and level of confidence either considerably influenced one another or both preparation and confidence in tandem seemed to influence in the number of gaps encountered during instruction.

CHAPTER 6

CLASSROOM PRACTICES RELATED TO LEARNING FROM TEACHING

This chapter focuses on the fourth research subquestion: What teaching practices can help teachers better recognize and address gaps in their content knowledge? When the teachers recognized gaps in their science content knowledge it was often a result of classroom practices that had the potential to facilitate teacher learning from practice, even if learning from teaching was not a primary reason for engaging in these practices. Other practices seemed to prevent teachers from recognizing or addressing the gaps in their science content knowledge. Some of the practices addressed in this chapter were visible during the observations; others became apparent as teachers shared general thoughts and feelings about their teaching practice during the interviews.

Most of the practices that seemed to facilitate or hinder learning from teaching related to teachers' classroom interactions with their students. There was also some evidence that the level of daily preparation to teach and how teachers dealt with discrepancies between the curriculum and their own conceptions had some influence on learning from practice. These practices, however, were previously addressed in Chapters 5 and 4, respectively, and will not be discussed further in this chapter.

With regard to practices related to interactions with students in the classroom, as noted in Chapter 2, classroom discourse is an important factor that can facilitate learning from teaching practice (see Akerson, Flick, & Lederman, 2000; Da-Silva, Constantino, Ruiz, & Porlan, 2007; Jones, Carter, & Rua, 1999). As a result of interactions with their students, the teachers in this study encountered 40 events that indicated gaps in their science content knowledge. These interactions with their students came in the form of student errors, student questions, student responses or ideas, inconsistencies in student data, and dismissing plausible student ideas. The teacher interactions with students that seemed to potentially facilitate or hinder teacher learning from practice fell into three basic clusters: (a) the teacher's transparency about her own fallibility (b) encouraging or discouraging student input in the classroom; and (c) adjusting instruction based on responding to and/or following up on unexpected student input.

Transparency about Teacher Fallibility

As shown in previous chapters, teachers had numerous opportunities in the classroom to encounter and address gaps in their science content knowledge. Even when teachers do not encounter SMK gaps, there are still potential gaps in their PCK that will likely be encountered in the classroom. In some cases, these gaps are also accompanied by teacher mistakes or errors in the classroom. In other cases it is a matter of teachers admitting to themselves and/or their students that they do not know the answer to a student question or do not know why the experiment did not work the way it was "supposed to." Throughout the data there were examples of teacher fallibility in the classroom. Teachers expressed varying levels of transparency about this fallibility. In some instances teachers were very willing to openly confront their lack of knowledge in front of their students. In other instances teachers were less transparent with their students regarding their own lack of knowledge.

Practices that Promote Transparency

Some of the teachers shared how they tried to openly confront their lack of knowledge in front of their students when they did not know the answer to a question or when they had made mistakes in front of their students. For example, when students had asked her questions and she was unsure of the answer, Ms. Lane said she usually turned to the computers in her classroom. She tried either to look the information up immediately online or sent one of her students to a classroom computer to research it on the Internet. She also stressed that she made sure that her students knew it when she was unsure about an answer. As she put it, “they know that I’m not gonna tell them wrong... [or] just make something up so it will sound like I know what I’m talking about, so I will ask them to go look [online] and I will look as well.” During one of her observed classes Ms. Lane realized that the pictures she was using for the respiratory system were not as detailed as she needed so she looked for other another one during class. When asked why she chose to search for it in front of the class she responded, “I like them to see me go through finding information because it is just as accessible to them as it is to me... so I don’t mind at all them seeing me pull up images… and information because just like I can do it, they can do it too.”

Ms. Lane also said that she was open with her students when she made mistakes or was unsure of something in class:

> When I’ve made a mistake I admit that I’ve made a mistake, and I think it is good for them to know that I make mistakes too… I don’t mind admitting when I do something wrong or when I mess something up… and I think that they know that I don’t mind.

This happened in one of her observed classes when she was talking about the Heimlich maneuver and told her class she was not sure but she thought she said that the Heimlich maneuver was used to dislodge foreign objects from the esophagus, not the trachea. Although her statement was incorrect, she did clearly let her students know that she was not sure about the information she was giving them. When asked about it she said,

> I don’t want to just keep talking like I know it matter of fact… This is something I need to look into because I’m not positive. I don’t like them to just think I know everything, especially when I’m not sure of something. I could have very well kept talking and they

would have never known the difference, but I didn't. I don't know, and I don't want them to think that I do.

Ms. Ardis talked about similar approaches in the classroom. When asked about her typical responses when students asked questions she did not have the answer to, Ms. Ardis said it did not happen often, but when it did happen she would say something like, "I don't know, but we can find out." She further expressed that she was not afraid to let her students know when she did not know something. "I'm very open to letting them know I'm learning right along with them as we go," she said. Additionally she made sure her students knew that she had to review some of the information she was teaching because it had been so long since she learned it. Ms. Ardis also said that one of her students once stated, "You're the teacher. How come you got it wrong?" She said she explained to the student that it was OK for teachers and adults to be wrong sometimes and "the best thing to do is correct yourself so you don't go on allowing someone [else] to know the wrong thing." She further explained that if she had explained a concept to her students incorrectly and realized her mistake she would "go back and explain it to them [again] to make sure they [knew] what [she] said was wrong… and why it was wrong." As she put it, "If they know I'm wrong it is… not a big deal..."

For these two teachers, their transparency with their students about their own fallibility allowed them openly recognize and address the some of the gaps they encountered in the classroom.

Practices that Avoid Transparency

Conversely, some teachers shared experiences during which they purposefully tried to keep their students from knowing when they had made a mistake or when they did not know something. For example, when asked if she was concerned about her students realizing she was wrong about something, Ms. Beam explained that she tried to get the content right so she did not make mistakes in class partly because her students were very blunt about pointing out her errors. One example of this occurred during an observed class when she deflected a student question about the safety issues with a solution they were using. When the student asked if the solution was safe to touch their skin, Ms. Beam simply said “don't put your finger in it.” In the interview it became clear that Ms. Beam was unaware of the safety precautions that were on the label of the powder she used to make the solution. Consequently, it seemed she was deflecting the student question to avoid letting her students know she did not know the answer to the question.

Another teacher, Ms. Mepps, talked about setting up a project for her students to complete so that they could teach her a biology concept she was confused about. As she put it, it worked really well and she was able to learn from their work through helping them with it. She also pointed out, however, that her students had no clue they were teaching her, and “you don’t tell them that.” She added that if she realized she had made a mistake in class, she would turn the class away from that concept before getting into it further. As she put it, “if I can avoid it and move your attention to my left hand while my right hand is trying to fix the mistake I just made, I will do it just like a lot of teachers. No one wants to look stupid in front of 30 kids.” Additionally, Ms. Mepps said she had sometimes hurried through the notes to avoid answering questions from students that she might not be able to answer. She explained that she did this so she would have more time to look it up for the next day. She also pointed out, however, that she realized this often intentionally discouraged her students from asking questions in the first place (therefore limiting her opportunities to learn from her students). Ms. Mepps also said that, although she usually intended to look up information after class, she often forgot about it and the issues remained unresolved.

It seems reasonable (based on these examples) to state that if teacher misconceptions and/or errors are not addressed when the teacher encounters them in the classroom, the opportunities to learn from these experiences can be limited. This can happen both because the teacher is not inviting the input of her students to assist in her own learning process and because it is possible that she will forget to look up the relevant information when she may have more time after school.

Student Input in the Classroom

This study has already shown that interactions with students in the classroom can illuminate and/or make teachers aware of gaps in their science content knowledge. With 40 observed instances in which teachers encountered knowledge gaps as a result of interactions with their students, certainly teachers' practices with regard to student input in the classroom can have an impact on whether and how teachers recognize the gaps in their own science content knowledge. All six teachers shared ideas on how to encourage student input in the classroom. Yet some of the teachers also talked about times when they had intentionally discouraged student input.

Encouraging Student Input in the Classroom

All of the teachers advocated creating a classroom environment that encouraged student input in their interview responses. Ms. Kidd said she enjoyed when her students got excited about science and got their hands dirty. She made sure to create a classroom environment where her students knew it was OK to be wrong. She said this was

> especially important because these kids are yelled at for being wrong their whole lives and so [they are] used to being wrong. I like to tell them in here… it is OK to be wrong

> because some of the best scientific discoveries were made because somebody was wrong and it turned out really well.

She explained this had helped her students "really open up more [so they would] try more things and be more creative if they [knew] it [was] ok if they [were] wrong and I [was] not going to yell at them." As a result of creating an open atmosphere in her classroom where her students were not afraid to express their thoughts and ideas, Ms. Kidd said that she sometimes learned from her students, which was fun and exciting for her, especially when they had better ideas than her. For example she said that they would "compare something [she was] talking about to something they [had] experienced…" and she would think to herself "Oh, I've never thought of it that way" or "that is a comparison that I never thought a seventh grader would make." She also said those experiences helped her think about what else she could compare to the concept or idea that her students would be able to relate to. Consequently, the experiences opened "up doors when [she could] learn to compare things differently for [her] kids and show them… other things that relate[d] to [the concepts] in their daily lives."

Similarly, when Ms. Beam was asked about an incident when she did not elaborate on a student's suggestion that perhaps the batteries they were using in an inquiry lab had drained energy between taking them out of the charger and putting them in a flashlight, she said "I didn't want to say 'that is absolutely wrong, no.'" She further explained that she did not want discourage him from sharing his ideas in future classes by telling him he was wrong in that instance.

In one of the observed classes, Ms. Keller was explaining the differences between positive, negative, and neutral charges. One of her students, however, did not know what neutral meant. Before Ms. Keller came up with an alternative explanation, another student in the class explained that it was like neutral in a car. He explained that a car is not in forward or reverse when it is in neutral. The explanation seemed to work for the student with the question, so Ms. Keller validated it and moved on. When asked about the experience she said, “I had no idea that a kid wouldn’t know what neutral meant, but in my head, before I could even think ‘how am I going to explain neutral?’ this kid pops out of his mouth the example.”

Additionally, although Ms. Mepps shared particular instances when she intentionally avoided student input that could have highlighted when she did not know something, she also said she was usually open to student input and tried to create an environment in her classes where students felt free to share their experiences and ideas. She told them not to be afraid to ask her if they thought something was different than she said, and she took time in class to address the ideas her students brought up. When there seemed to be a conflict of opinions she said she had turned “it into a learning experience and [they tried] to… come up with the real answer” as a class.

Many of these examples relate specifically to gaps in the teachers’ PCK knowledge of students, which is not surprising because this kind of knowledge cannot easily become apparent without teacher-student interactions. There were also instances, however, when encouraging student input in the classroom helped teachers recognize and address other types of SMK and PCK gaps. In order for teachers to be able to recognize gaps in their own knowledge as a result of student questions, comments or ideas, they must first create an environment where students feel safe and comfortable asking questions, making comments, or sharing their ideas. This can take place through creating an atmosphere where students are comfortable expressing themselves and know they will not be ignored; creating an atmosphere where students feel it is OK to be wrong; and having an attitude of utilizing student input in the classroom.

Discouraging Student Input in the Classroom

Although all six teachers recognized the importance of encouraging student input, some teachers also talked about times when they had found themselves discouraging student input. Teachers discouraging student input was also evident during some of the teacher observations.

As noted earlier, contrary to what she said about her general positive approach to student input, Ms. Mepps also shared that when she was less confident about what she was teaching, she sometimes tried to hurry through the notes to avoid having to answer questions from her students that she may not be able to answer. Sometimes she would

> tell the students we need to hurry through the notes and will get to it tomorrow because we’re running out of time... so they [wouldn’t] start asking me questions before I was ready to answer them. If I mention it that way a lot of times they won’t really want to ask questions. They’ll just want to get the notes done and then move on.

As mentioned above, Ms. Mepps did realize that this often discouraged student input, but she seemed more concerned about not knowing the content than encouraging student involvement in these instances.

Another way the teachers discouraged student input was by discounting students’ ideas during class. I observed this happening in Ms. Ardis's class on two occasions. One instance was when her student was having difficulty getting a light bulb connected to a small motor to illuminate by rubbing the motor on a rubber band. As noted in Chapter 4, he did find a creative way to light the small light, however, by rubbing the motor on the rubber of his shoe sole. He excitedly showed his teacher that the shoe sole worked better than the rubber band, but Ms. Ardis said “No, no, no! Don't do it on your shoe. It did work though. Is that rubber on your shoe? No don't do it again." When asked in the interview about this incident, Ms. Ardis said

> I didn't know if the shoe would mess up the motor so I didn’t want him to break it. But it was really cool that it worked on his shoe and I asked him if it was rubber because I knew they used rubber bands so I wanted to know if it had something to do with it. The shoe was thicker and you didn’t have to worry about it moving back and forth because it stayed in place. So I think it may be just that rubber smooth surface had something to do with it because it lit up really bright. I was shocked.

Although she did explain how impressed she was with his idea in the interview, the student appeared to take from the interchange only that he should not do it again. It is plausible to conclude the student may be discouraged from independently testing new ideas in the future.

It was in a later class that day that Ms. Ardis's student suggested that riding a skateboard up a ramp was an example of using an inclined plane to make work easier. As noted in Chapter 4, Ms. Ardis turned students away from that answer and suggested walking carrying boxes up a ramp (rather than lifting the boxes) to put them into a truck as an everyday life example of how a ramp can make work easier. It was evident in the interview that Ms. Ardis assumed the student was referring to a U shaped ramp which is not technically an inclined plane. Additionally, Ms. Ardis indicated she did not believe the skateboard example involved anything being pushed or pulled up the ramp, so it didn’t constitute work.

In this case, the student’s skateboard on a ramp could have been just as much an example of an inclined plane as Ms. Ardis’s ramp on a truck. Ms. Ardis, however, did not ask the student to further explain whether she was referring to a skateboarder riding up a straight inclined ramp or whether she was referring to a curved (half pipe) skateboard ramp. Although Ms. Ardis was correct in her assertion that a curved ramp is technically not an inclined plane in the simple machine sense, she incorrectly stated that nothing was being pushed or pulled up or down a skateboard ramp (that no work was being done). Ms. Ardis did not seem to realize that a human on a skateboard was the object being pushed up a skateboard ramp (work) and that the ramp made that work easier. Consequently she discounted the student's potentially correct idea while also possibly discouraging the student from giving other answers publicly in class.

The skateboard example with Ms. Ardis illustrates what can happen with regard to specific gaps in a teacher's knowledge when that teacher discourages student input in the classroom. It was apparent that Ms. Ardis was unaware of her own misconception that work could only occur and/or be made easier on an inclined plane but not on a curved ramp. Additionally, the fact that she discouraged the student's response, rather than asking the student to more thoroughly explain her thinking, meant that Ms. Ardis did not become aware of the gap in her own science content knowledge during the interchange. In this case it was evident that discounting the student's idea had a direct influence the fact that Ms. Ardis did not recognize the gap in her own science content knowledge that this student's comment illuminated. It also seems reasonable that discouraging student input in other ways (like the two other examples listed above) could also potentially curb teacher learning from practice by preventing teachers from encountering and/or recognizing gaps in their science content knowledge that could have been illuminated by student input in the classroom.

Unexpected Student Input

During the observed lessons there were many instances when a teacher encountered unexpected student input in the classroom. How teachers chose to respond to this input seemed to influence their recognition of the science content knowledge gaps they encountered. In some instances the teachers either adjusted their instruction immediately or changed their instructional strategies in a later class that day. In other instances the teachers either did not recognize or seemed to ignore the unexpected student input and did not adjust their instruction to address the issues that arose.

Adjusting Instruction in Response to Unexpected Student Input

One important aspect of teaching is the ability to adjust instruction based on student input, especially when that input is unexpected. Teachers can make these instructional changes in the lesson when the unexpected student input occurs or later in the day when teaching the same content to other classes. The practices teachers employed in responding to unexpected student input often also led teachers to encounter and recognize gaps in their own knowledge. Examples of unexpected student input include students making unexpected errors, a student coming up with a different and plausible idea for demonstrating or explaining a concept, and student questions or behavior indicating they do not understand what the teacher is teaching.

Ms. Keller gained a better understanding of how her students were thinking because of an error that many of them made when they were labeling the charges of protons, neutrons and electrons. In the first observed class during this visit, Ms. Keller simply told her students “N stands for neutral.” In the last class of the day, however, she said “N stands for neutral, NOT negative.” When asked about the difference between what she said in the two classes, Ms. Keller explained that in her earlier classes, when she asked her students to label the charges of protons, neutrons and electrons, many of her students said, “neutrons are negative.” She had not anticipated that error, so she emphasized that neutrons are neutral, not negative, in her later classes. Because of her students’ errors Ms. Keller realized she had not anticipated this common misconception and that she had not initially represented the content in a way that would address the misconception.

Additionally, when asked about aha moments in the classroom, Ms. Keller said she often had aha moments, often a result of something her students had brought up that she had never thought of or had not thought of in that way before. She also said that she would share the same idea with later classes that day when the topic came up. Ms. Kidd was also open to incorporating ideas presented by her students into her daily instruction. She explained that often students asked a question, commented on something or explained it in a way she had never thought about it before. In those instances she praised the students for their input and then usually used the new idea throughout the day with her other classes.

With regard to paying close attention to whether her students understood what she was teaching, Ms. Lane explained that if she realized that her students did not seem to understand the concepts she made changes throughout the day to accommodate them. In her case the first class of the day was her honors class, so she expected that they would grasp the concepts more quickly and aptly than her other classes. As she put it, “if something doesn’t work for them it definitely won’t work with the other classes.” When this happened she said she worked on making the necessary adjustments for subsequent classes during her planning period. During one observation, Ms. Lane used pictures from the Internet to explain the respiratory system in her first class. However, for her last class she had found different, more detailed, pictures to show to her class. She explained, “When I went over it with the first class I realized that the images weren’t detailed enough and didn’t show enough, so in my planning period I found some different images which you saw at the end of the day that… made it more clear.” Similarly, Ms. Keller talked about how she had become aware of her own knowledge gaps when her students struggled to understand what she was teaching. As she put it, “it is kind of a… if they’re completely lost, maybe I'm lost too, because... if I can't explain it or if I can't break it down, that means that I don't know my information well enough either."

Not Adjusting Instruction in Response to Unexpected Student Input

Conversely, I also saw instances when teachers did not adequately address unexpected student input. For example, the motor and ramp examples from Ms. Ardis class were also examples of the teacher not adjusting her instruction to accommodate the new information her students presented in class. In another example, Ms. Mepps said that when students asked questions she would often tell them she would look it up later so they could move on. Yet she admitted that she often forgot to look up the information so the student questions remained unanswered.

In another case, Ms. Lane was explaining an activity in which her students were to decide what bases would pair with a strand of bases if in DNA and what bases would pair with the same strand of bases for RNA. In her explanation, however, she said both "there is no T in RNA" and "what pairs with the T in RNA?" Although it was clear Ms. Lane understood the content, she was having trouble explaining it adequately to her students. It was also clear to both the observer and Ms. Lane that her students did not understand what she was saying. Yet instead of recognizing that their confusion may have been because the way she was explaining it was confusing, Ms. Lane simply repeated herself slower and louder. It was not until the interview that she became aware that perhaps her students were confused by what she was saying rather than just not listening as she had previously assumed.

Another example of not adjusting instruction in response to unexpected student input occurred when Ms. Beam did not realize that a student suggestion was the solution to a problem the class was having with an inquiry activity. Ms. Beam's class was conducting a battery lab/investigation out of a district provided kit. The investigation included small rectangular sheets of copper and zinc with blotter paper between them. This apparatus was held together with a rubber band and placed into a beaker filled with a copper sulfate solution. The ends of the two metal sheets were bent away from each other at the top and a wire for a small light bulb was taped to each one, creating a closed circuit. As mentioned previously, none of the observed batteries worked properly, and Ms. Beam's lack of preparation for the activity most likely contributed to her inability to adequately troubleshoot. While she was re-taping wires and fretting that she had mixed her solution wrong, however, one of her students accurately described what was going wrong with the experiment. This student noticed that the blotter paper between the copper and zinc was still dry when her group took their battery apart. Ms. Beam praised the student for her observation and pointed this idea out to the rest of the class as a possible reason why the experiment had not worked, so this was not an example of discouraging student input. Yet Ms. Beam did not follow through with the idea or test it by wetting the blotter paper, which was probably one reason none of her students' batteries worked that day.

In another example, during one observation Ms. Mepps accepted any answers her students came up with even if the responses conflicted with other student answers or the answers provided in the book. Ms. Mepps said that if she could not easily come to terms with conflicting student viewpoints on the same concepts in class she simply chose not to count it against her students, choosing instead to move on rather taking up class time to figure out from other sources which viewpoints were correct and which ones may have had errors. It seemed she was willing to discard ideas if she was unsure whether they were correct rather than taking time to work through the answer based on evidence and outside sources. As she put it,

> I let the kids have some type of ownership for it. In one class they can think it is one way and the next class the other way but if they truly have a good argument for it I never count it wrong... [and] if I can't prove to them it is one way or the other there is not really much to do. They can argue it and I can argue it... they get credit for it but those are the kind of questions you just omit out and move on.

This practice seemed to negatively affect both her own learning as well as her students' learning because she chose not to address these misconceptions with her class or on her own.

Summary

The three areas of classroom discourse addressed above each seemed to fit into a continuum of practice that ranged from facilitating to hindering the potential to learn from teaching practice (see Table 6.1). With each of these continuums, the practices that facilitated teacher learning from practice did so because they potentially helped teachers come in contact with, recognize, and engage with the gaps in their science content knowledge. Conversely, the practices that seemed to potentially hinder learning from practice did so, at least in part, because these practices prevented teachers from either recognizing or engaging with the gaps in their science content knowledge. In some cases this seemed to be a conscious choice, but in other cases the teacher simply did not have enough prior knowledge to recognize the opportunities to learn from practice that they were potentially missing.

Table 6.1
Continuums of Teacher to Student Interactions Related to Teacher Learning from Practice

Practices that can Facilitate Teacher Learning from Practice	Practices that can Hinder Teacher Learning from Practice
Transparency about teacher fallibility and teacher classroom errors	Avoiding transparency about teacher fallibility and teacher classroom errors
Encouraging student input in the classroom	Discouraging student input in the classroom
Adjusting instruction in response to unexpected student input.	Not adjusting instruction in response to unexpected student input

It is important to note that the teachers did not generally fit completely into one side or the other of these continuums, but often talked about practices that were both positive and negative relating to their classroom discourse practices. Consequently, some of the same teachers fit into both sides of these continuums of practice depending on the situations. This seems to suggest that how teachers respond to classroom discourse can change depending on the situation.

CHAPTER 7

DISCUSSION

This dissertation study is part of a research agenda that focuses on how teachers learn science content from their own teaching practice. The study is based on three important assumptions about teachers' science content knowledge: (a) the necessity of adequate science content knowledge for teaching science (Ball, 2000; INTASC, 2002; NRC, 1996; Shulman, 1986); (b) that elementary and secondary preservice education programs are not providing all of the science content knowledge teachers need to teach science subjects effectively (Akerson, 2005; Ball, 2000; Feiman-Nemser, 2001; Hoz, Tomer, & Tamir, 1990; Lemberger, Hewson, & Park, 1999; Roehrig & Luft, 2004; Smith & Neale, 1989); and (c) that significant teacher learning takes place as teachers teach in their own classrooms (Akerson, 2005; Akerson, Flick, & Lederman, 2000; Roehrig & Kruse, 2005; Sherin, 2002; Osborne, 1998). These assumptions framed the main research question: When do middle-school science teachers recognize gaps in their content knowledge? This question was addressed through data collection and analysis related to four subquestions: (a) What classroom events serve as potential indicators of gaps in teachers' knowledge? (b) Do certain classroom events trigger teachers' recognition of gaps? (c) How does the depth and nature of teachers' knowledge affect their content knowledge gaps? and (d) What teaching practices can help teachers better recognize and address gaps in their content knowledge?

This chapter begins with a brief summary of the research findings, followed by discussion of the limitations of this research, implications for teaching and instruction, and what future research may be needed to address questions encountered during this research but for which the data were not sufficient to address in the previous chapters.

Summary of Findings

This exploratory research focused on teachers encountering gaps in their science content knowledge during teaching practice. Analyses provided evidence of gaps in teachers' science content knowledge, the types of classroom events that seemed to act as indicators of these gaps, and whether teachers recognized the gaps in their knowledge. The research also examined the relationships among teachers' prior knowledge, their confidence in that knowledge, and daily preparation to teach. Further, the research examined classroom discourse practices that facilitate or hinder teachers' learning from practice.

Gaps in Teachers' Science Content Knowledge

The observations and interviews of the teachers in this study revealed that under certain conditions some common classroom events acted as *potential gap indicators*—observable actions or behaviors (by the teacher or students) or events in the classroom that suggest possible gaps in a teacher's knowledge. In this study I identified 151 of these potential gap indicators; 114 of these events actually indicated gaps in the teachers' science content knowledge. Many of the classroom events that indicated gaps in the teachers' science content knowledge were similar for many or all of the teachers being observed. These events related to the teachers' actions in the classroom (teacher instruction) and student input in the classroom. Examples of events relating to student input included student questions, student errors, student responses, and inconsistent student data that related to gaps in the teachers' science content knowledge. Examples of events relating to teachers' instructional activities included teachers making changes in their lessons, looking up information in class, needing an alternate explanation for a concept in class, and encountering errors or inconsistencies in their curriculum materials, all of which illuminated gaps in the teachers' science content knowledge.

Additionally, gaps were often indicated through series of related events involving interactions between teachers and their students. In some cases the initial learning triggers (such as a student question or error, or unexpected outcomes in the classroom) also acted as the gap indicators. In other cases the gap indicators were only visible because of the teacher's actions after she had recognized the gap and was attempting to address it (such as looking up information in class or making changes in her instruction from one class to another).

It is also important to note that most of the teachers' observed interactions with their students in the forms of student questions, student errors, or student ideas were normal classroom interactions in which the teacher was adequately equipped with the necessary science content knowledge to address the student questions, errors and/or ideas. This is important because the only times these types of events in the classroom have the potential to indicate gaps in the teachers' science content knowledge is when these events connect to actual gaps in the teachers' science content knowledge. Consequently, not every interaction with students should be immediately thought of as a potential gap indicator.

The lines of questioning in the follow-up interview protocol (Appendix B) were designed to help determine whether a teacher had actually encountered gaps and: (a) whether the teacher recognized the gaps in her science content knowledge on her own (either at the moment the gaps were illuminated or as a result of her own reflective practice); (b) whether she recognized the gaps because of the interview process (watching the video or talking about the classroom events); or (c) whether the teacher did not recognize the evident gaps in her knowledge. The process for making these determinations was validated with strong interrater agreement (see Table 3.5).

The teachers in this study encountered both subject matter knowledge (SMK) and pedagogical content knowledge (PCK) gaps during the observations. In general, teachers encountered more PCK gaps (83) than SMK gaps (34). Additionally, they recognized a greater percentage of their PCK gaps (89%) than SMK gaps (65%) (see Table 4.2). One possible explanation for these discrepancies is that PCK is dependent on the SMK being taught as well as the teaching context (including the students being taught), so it can be difficult to anticipate and learn during preservice education (Barnett & Hodson, 2001; Loughran, Mulhall, & Berry, 2004). Consequently, for any given science topic or concept, teachers may often have adequate SMK without having adequate PCK, but it is less likely for teachers to have adequate PCK without first having adequate SMK. For example, a teacher may clearly understand a science concept (SMK) without knowing the best ways to represent that concept so that middle school students will be able to understand it (PCK).

Whether teachers recognized the gaps in their science content knowledge seemed to be dependent on the unique context in which the teachers encountered those gaps. There were some gap indicators, however, that seemed more likely to lead to teachers recognizing their science content knowledge gaps and others which seemed less likely. For example, the teachers recognized all of their gaps when they looked up information in class, when they had moments of insight, and when they needed an alternate explanation or representation for a concept in class. Similarly the teachers recognized all but one gap when they made deliberate changes in their lessons. In these cases, however, the classroom behaviors indicated gaps because the teachers had already recognized gaps in their knowledge had attempted to bridge the gaps in class. Teachers recognized about two thirds of their gaps when they encountered errors or inconsistencies in their curriculum materials, and they also recognized most of the gaps illuminated by unexpected outcomes in the classroom (such as an experiment not working the way it was expected to). Conversely, teachers recognized less than 50% of the gaps they encountered when they or their students made content errors in the classroom. The teachers also did not recognize any of their gaps when they presented incongruent content in the class or dismissed plausible student ideas (Table 4.3).

It is important to note, however, that these were not clear patterns with regard to recognizing gaps based on particular events. Whether teachers recognized their gaps depended on the varied contexts in which they encountered those gaps; no systematic patterns emerged to indicate types of classroom events that might lead future teachers to recognize or not recognize gaps in their science content knowledge. The teachers' levels of cognitive attentiveness to these events and their levels of reflection-in-practice and willingness to address potential gaps seemed to influence the likelihood of recognizing science content knowledge gaps and potentially learning from them. Still, it is unclear what it is about particular potential learning triggers that made them actual learning triggers for the teachers in this study. Much of that process relates to the teachers' thought processes as they encountered the gaps in their science content knowledge. Although it was clear from the data when teachers encountered gaps and whether they recognized the gaps, the current research did not reveal why they recognized or failed to recognize the gaps they encountered.

Teachers' Previous Knowledge and Observed Gaps

Teachers' background knowledge played a role in the number of gaps they encountered on a given instructional day. This study examined background knowledge in terms of the teachers' preservice undergraduate science coursework, their own perceived confidence in their knowledge of the subjects they were teaching, and the extent of their daily preparation to teach the observed lessons.

In general, the teachers' undergraduate coursework was too similar to suggest any relationships between the amount of science coursework and the numbers of gaps observed during teaching. For one teacher, though, there was a misalignment between her college coursework and the subject she was teaching. Ms. Beam was teaching physical science but had not taken any college-level physics courses. She suggested that because of this disconnect she would have been more comfortable teaching life science than the physical science class she was teaching. This supports the findings of other research (Kinghorn & Britton, in preparation) and suggests that when there is a misalignment between a teacher's post-secondary coursework and what she is teaching, she may encounter more science content gaps while teaching.

Because the number of post secondary science courses the teachers completed was not a good measure of differences in teachers' prior knowledge in this study, another indicator of teachers' prior knowledge was their expressed confidence in their knowledge of the subjects they taught. This study examined each teacher's individual expressed levels of confidence for both visits. Generally, the teachers encountered fewer gaps in their science content knowledge during instruction when they were more confident in their knowledge of the subject matter they were teaching. When the same teachers were less confident about their knowledge of the subject they were teaching the number of gaps they encountered generally increased. Confidence alone, however, was not the only factor that seemed to influence the number of gaps each teacher encountered during each observation. The level of preparation to teach the observed classes also seemed to affect the number of gaps teachers encountered. The less prepared a teacher was to teach, the more gaps she encountered on that instructional day.

Two of the teachers with high levels of confidence and high levels of preparation for both visits encountered relatively few gaps during both visits. It was unclear, however, how much influence confidence and preparation each had on the number of gaps and in what ways adequate preparation may have influenced their expressed confidence. The teachers who expressed higher levels of confidence during one visit and lower levels during the other visit encountered fewer gaps on the days they were more confident and more gaps on the days they were less confident. Additionally, teachers who had better prepared to teach during one instructional day than they had on the other day encountered more gaps when they were less prepared and fewer gaps when they were more prepared.

These findings suggest four different ways teachers' prior knowledge can affect the number of gaps they encounter during classroom instruction: (a) a mismatch between what a teacher teaches and what she studied in college can lead to more gaps encountered in the classroom; (b) generally, when individual teachers are more confident in their knowledge they encounter less gaps than when they are less confident; (c) generally, the more a teacher prepares to teach a particular lesson, less gaps she will encounter during the presentation of that lesson; and (d) the levels of confidence and daily preparation to teach can interact with and influence one another to affect the numbers of gaps teachers encounter during instruction.

Classroom Practices Related to Learning from Teaching

Throughout the observations, interviews, and analysis I looked for examples of teacher practices that seemed to facilitate or hinder learning from practice by recognizing and addressing gaps in their content knowledge. These examples came both from the observations and from teacher responses during the interviews. Teachers' interactions with their students fell into three continuums of practice: (a) the level of teachers' transparency about their own fallibility and errors, (b) the level of encouraging student participation in the classroom, and (c) whether and how teachers adjusted their instruction based on unexpected student input during classroom instruction. The continuums are interrelated and, depending on the instance, each of the teachers fell on both sides of each continuum at different times during her teaching practice.

It seemed that the more willing a teacher was to admit to her students that she did not know something or had made a mistake, the more likely she was to recognize the gaps in her knowledge that had the potential to lead to learning from her own teaching practice. Similarly, if a teacher was afraid or unwilling to let her students see her content knowledge weaknesses, the opportunities to address those gaps in the classroom were more limited. With regard to student input in the classroom, it seemed that the more willing a teacher was to encourage student input in the class the more opportunities she had to encounter new information as a result of that input. On the flip side, if a teacher discouraged student input (intentionally or unintentionally) the opportunities to potentially learn from her students decreased. How teachers responded to unexpected student input in the classroom also seemed to affect whether they learned from their own teaching practice. If a teacher chose to adjust her instruction based on student input it often led to potential learning experiences for both her and her students. Conversely, when teachers did not adequately address pertinent student input by adjusting instruction, they often did not recognize the gaps in their own knowledge that the student input may have been illuminating.

Limitations

The most obvious limitations of this research concern the sample of teachers who were observed and interviewed. The first issue was the small number of teachers observed and the fact that each teacher was only observed teaching twice during the instructional year. To help offset this limitation, each teacher was observed teaching in a different unit than she had been teaching during the previous visit. I observed patterns in the data related to what factors influence the science content knowledge gaps teachers can encounter, ways teachers recognize these gaps, and some classroom practices that can promote or hinder learning from practice. Still, given the small sample size, it is not possible to make general claims about these patterns.

The next issue was that this convenience sample of teachers was not as diverse as it could have been. Although the teachers came from urban, rural and suburban schools in three different states, all of the teachers were female and each had traditional or emergency secondary teaching credentials. Consequently, with no elementary-certified teachers, it was not feasible to make comparisons between teachers' science background knowledge (as defined by the science courses they completed in college) and the evidence of science content knowledge gaps teachers encountered in the classroom while they were being observed. Likewise, there was no opportunity for comparisons between male and female teachers.

Other limitations were evident because of the nature of the qualitative research methodologies employed to collect and analyze the data. First, although they provide the advantages of observing phenomena in their natural settings and the opportunity to explore each teacher's observations and interviews in depth, the qualitative methods used for this research prevented generalization of the findings to the larger population of new middle-school science teachers. It was interesting and compelling, however, to see similar classroom experiences that illuminated gaps, similar reactions to these gaps, and similar classroom behaviors that seemed to facilitate or hinder learning from practice from teachers in urban, suburban and rural schools in three different states.

As noted in Chapter 3, observations and interviews each have limitations: It is difficult, if not impossible, to understand teachers' cognition, thoughts, knowledge and intentions from observations alone, and it is similarly difficult to corroborate what teachers say in interviews alone. By conducting both observations and follow-up interviews together these potential limitations were curtailed, but not completely eliminated. The very acts of observing and questioning these teachers had the potential to influence the ways they thought about, processed, and approached their teaching practice, especially with regard to the gaps they encountered during their classroom instruction. Similarly, the act of watching video segments of their teaching during the follow-up interviews likely could have caused them to subconsciously alter their perceptions about what had happened during those classroom events. Consequently, it is impossible to know with certainty whether the teachers' responses were mostly recall of their thoughts of the events as they happened, mostly recall of the events based on the changes in their thinking that may have occurred as they reflected on their teaching either before or during the interview, or a combination of these conditions.

I anticipated these potential limitations and interferences and designed the interview protocols so that the purpose of the research seemed to be about teaching practice in general, rather than mostly about encountering gaps in science content knowledge. Additionally, the interview protocols, especially when teachers were recalling events that had taken place during the observations that day, included questions designed to inquire about any changes in thinking that may have taken place between the event and the interview. With these questions I hoped that if the teachers' thinking had changed they could think about the possible contrasts in their thinking from the moments being discussed to the moments when the discussion was taking place during the interviews. This line of questioning also helped determine whether the teachers had recognized the gaps in their science content knowledge on their own (either at the moment they were illuminated in the classroom or as a result of their own reflective practice) or if that realization had come because of the interview process (while watching video clips of their teaching practice or because the questions they were asked made them think about the events in different ways). Although the research design controlled for some of the inherent limitations of the research methods, the teachers' responses may have been unintentionally and unknowingly influenced by my observations and interviews, so it is possible some of their responses do not accurately reflect what they were thinking during the observed moments of their classroom teaching.

Another problem with interview data is that it can be difficult for teachers to verbalize their conscious and subconscious thoughts about events or phenomena when they are questioned about these events. Similarly it is difficult to tap the type of knowledge deficiencies I was looking for when it was necessary (to avoid unnecessary researcher influence in the teachers' responses) not to clearly state that I was seeking evidence of gaps in the teachers' science content knowledge. In response to general queries about moments in the classroom with evidence the teacher may have encountered a gap in her knowledge, the teacher may have recognized the gap in her knowledge. For whatever reason, however, the teacher may have focused on some other aspect of the classroom event in her response. It is probable that even when there was unobservable evidence that she had recognized the gap in her knowledge, that evidence may not have been expressed verbally in the interview, even after further probing questions. Likewise, being unaware of the purpose of the study, a teacher who had not actually encountered a gap during one of the observed potential gap indicators may not have thought to explain that she really did know the concept(s) in question during the interview process. This could have resulted in an incorrect assumption of a gap followed by an equally incorrect assumption that the teacher failed to recognize the nonexistent gap.

Because of these potential issues with and limitations of the observation and interview data, it was important to have a second individual look at the observation videos and read the teachers' responses to determine whether there was a gap in the teachers' knowledge, whether the teacher recognized the gap in her knowledge, and when the teacher recognized the gap in her knowledge. The high level of interrater agreement (see Table 3.5) served to validate the coding methods and assuage some of the concerns that what was being observed and what teachers said may have been misinterpreted. The high interrater agreement also limited concerns about the subjectivity of the coding procedures.

There was a greater level of subjectivity, however, in determining the level of daily preparation to teach each lesson and the level of confidence each teacher had for the science content she was teaching for each observed lesson. As noted in Chapter 5, the influence of the level of preparation to teach emerged from the data when it was clear that daily preparation to teach could seemingly override a teacher's confidence when it came to the number of gaps she encountered in the classroom. Additionally, although I attempted to clearly explain how I made judgments about the level of teachers' confidence and preparedness, the operational definitions were rather loose. I recognized that fact but still chose to make some judgments about these factors based on the data collected, and I felt that the limitations of these loose definitions were only marginally detrimental to the research as a whole. Although I believe the data and analysis were worthwhile, future research would be helpful to better operationalize the definitions and to gain a better understanding of the interrelationships between confidence and preparation and how these factors can influence the science content knowledge gaps teachers encounter in the classroom.

Although this research had many inherent possible limitations, I was able to plan and account for these limitations so that they had limited total impact on the outcome of the data collection and analysis. Further, because this was an exploratory study and because each teacher's experiences are inherently unique and teachers' opportunities for bridging gaps are as varied as their experiences, a comprehensive definitive answer to the question about when teachers recognize gaps in their science content knowledge in general was not possible or necessarily desirable. Instead this research detailed patterns of practice that may have influences (depending on the situations) on how and when teachers may encounter and recognize the gaps in their science content knowledge during their classroom teaching practice.

Implications

This research has a number of implications for teacher practice and teacher training as well as for future research.

Implications for Teaching Practice and Teacher Training

The research findings include specific cases of classroom situations and events (and sequences of events) that have the potential to indicate gaps in teachers' science content knowledge. The data also suggest teaching practices that may influence the recognition of gaps encountered while teaching. One of the most notable implications of this research, then, is the suggestion that teachers should be aware that they may encounter gaps during their teaching practice and that they should actively search for gaps in their science content knowledge when they encounter events, situations, or teaching practices similar to the ones in this study. If teachers employ a reflective approach to their teaching practice by proactively looking for and becoming more aware of similar events or situations in their own classrooms, they may increase their ability to recognize and effectively bridge their own science content knowledge gaps.

Similarly, preservice teacher educators, teacher mentors, and teacher induction and professional development providers, can use the findings of this research to help teachers develop more effective approaches to reflective teaching practice.

For example, whereas neither of the two teachers who dismissed plausible student ideas recognized that they had done so (see Table 4.3), I hope that other teachers can become more aware that unexpected student input can still be valid (and can illuminate teacher knowledge gaps) even when is the student input is not consistent with what the teacher was expecting. The implications of this knowledge may result in teachers becoming more open to learning from their students. Additionally teachers who are more aware of these potential gap indicators because of this research may be more willing to embrace their lack of knowledge in the classroom in order to promote learning experiences for both themselves and their students. I anticipate they will realize that encouraging student input can be an excellent way to learn more about their students and to encounter gaps in their own knowledge in ways that can lead to learning from practice. Further, this research could help teachers approach common classroom events (such as instructional inconsistencies, addressing inconsistencies in curriculum materials, or encountering inconsistencies in student data) from a perspective of learning from practice, which could then help them to better consciously recognize and address the gaps they encounter in their science content knowledge. Finally, this research may help teachers become more aware that student errors, questions, and responses can clearly illuminate gaps in the teacher's own knowledge as well as gaps in student knowledge.

Similarly, being more aware of these potential gap indicators can help individuals who train and support teachers as they observe and assess preservice and early-career teachers' teaching practice. This may occur when those who train and support teachers are able to more clearly notice when teachers encounter gaps in their science content knowledge (whether the teachers recognize those gaps or not) and then help teachers to: (a) recognize the gaps; (b) recognize learning triggers and gap indicators evident during classroom instruction; (c) work on bridging those gaps; and (d) use these experiences to help teachers facilitate dispositions of reflective teaching practice that can potentially influence future learning from practice.

As noted in Chapters 1 and 2, preservice teachers who had opportunities to engage in authentic scaffolded teaching experiences early in their preservice education showed more developed PCK in their student teaching experiences (see Zembal-Saul, Blumenfeld, & Krakcik, 2000; Zembal-Saul, Krajcik, & Blumenfeld, 2002). In other words, these preservice teachers had opportunities to encounter gaps in their PCK knowledge (specifically content representations) during these early supervised teaching experiences. The result of encountering these gaps was that their PCK was notably more developed during their student teaching experiences. The findings of the present research study suggest that early-career teachers will likely encounter more PCK gaps than SMK gaps for any given concepts during classroom instruction. Consequently, it is important to help preservice teachers understand the nature of PCK and how it can be encountered and learned within the context from practice, something the findings of this research can help address.

Although it is expected that preservice teachers would learn from scaffolded teaching experiences, early-career teachers also learn from their teaching practice as they encounter gaps in their science content knowledge and address those gaps (see Akerson, 2005; Akerson, Flick, & Lederman, 2000; Roehrig & Kruse, 2005; Osborne, 1998). As stakeholders in teacher education, induction, and professional development are able to better understand the processes of learning from practice (particularly in relation to how and when teachers encounter gaps in their science content knowledge during classroom instruction), they may also be able to better equip teachers with the tools they will need to successfully engage in reflective teaching practice that leads to effective learning from practice.

As the influence of this research helps equip preservice and early-career teachers with tools for learning from practice, they may be better able to intentionally approach learning from reflective practice rather than resorting to the trial and error approach to learning from practice that seemed the norm for the teachers in this study.

Another potential implication of this research relates to the ways in which teacher professional development workshops (especially those that relate specifically to kit-based inquiry activities like the ones Ms. Ardis and Ms. Beam attended) may have a negative influence on how adequately teachers prepare for those particular lessons beyond what they did in the workshop. Both Ms. Beam and Ms. Ardis suggested that because they had attended professional development workshops for the inquiry activities they were teaching, they had prepared less for those activities than they would have if they had not attended the workshops. They also expressed relatively high levels of confidence in the content they were teaching, but each encountered a relatively high number of gaps (many of them unrecognized) during those observed lessons. It was also clear that the fact they had not adequately prepared to teach those lessons was an influencing factor in the gaps they encountered and whether they recognized those gaps.

Additionally, the lack of preparation on both teachers' parts led to major troubleshooting issues with the activities that they may have been able to address if they had taken more time (in Ms. Ardis's case) or any time (in Ms. Beam's case) to prepare for the lesson before class. It is important to note that this last statement is rather speculative, but the concern that the professional development workshop may have negatively impacted these teachers' perceived need to fully prepare to teach those particular lessons does warrant further investigation through potential future research that will be discussed below.

Implications for Research

As expected with an exploratory study, collecting and analyzing data led to additional questions that the data hinted at but could not adequately address. These questions raise interesting issues for future research in and understanding of the processes teachers go through as they learn from practice. First, because this research was framed using the model for teacher learning from practice, it is reasonable to explore future research possibilities that address additional aspects of that model. Additionally, there were questions about the interrelationships among confidence, daily preparation to teach, and gaps, as well as questions about how professional development may have an effect on teachers' daily preparation to teach particular lessons. Potential future research that will address these questions is discussed below.

Additional research using the model for teacher learning from practice. The framework for this research was based on the preliminary study that included interviews with 10 elementary-school teachers to get a better understanding of how these teachers perceived that they had learned from their own teaching practice (Kinghorn, 2008). The model for teacher learning from practice (Figure 1.1) was a result of this preliminary study, and the current study focused on the parts of the model when teachers encounter gaps in their science content knowledge during teaching practice. Consequently, the scope of this research was limited to identifying potential learning triggers and potential gap indicators in the classroom, identifying actual gaps in the teachers' science content knowledge, and determining whether the teachers recognized the observed gaps. In addition to corroborating the findings of the preliminary study (which were obtained only through self report interviews), the current research also identifies other classroom events that have the potential to act as learning triggers and/or potential gap indicators. Additionally, the current study identifies some teacher practices that seemed to either facilitate or hinder the teachers when it came to recognizing the gaps they encountered in their science content knowledge.

Although the present study has developed a workable typology for determining when and how teachers encounter gaps in their knowledge and whether they recognize those gaps, more focused study is needed to address why teachers recognize or fail to recognize their science content knowledge gaps. A question for future research to address this issue could be “What happens as teachers access their current content knowledge in the context of potential learning triggers in the classroom?” The preliminary study and this dissertation both addressed understanding the nature of potential learning triggers and potential gap indicators in the classroom. Yet understanding the nature of these common classroom events is not enough. We must also understand the ways teachers think about potential learning triggers which can then activate them as actual triggers for learning which facilitate teachers’ to recognition of their own science content knowledge gaps.

The present study did not include the kinds of questions that would tap into the cognitive processes that determined why one teacher recognized a gap from a student question and why another teacher did not (or even why the same teacher may have recognized the gap in one instance and not in another when the learning trigger was similar or identical). Future research in this area would include similar methods. I would first go through the similar process of identifying potential gap indicators through classroom observations, determining whether they indicated actual gaps, and determining whether and when the teachers recognized the gaps through follow-up interviews. Then, instead of carefully avoiding informing teachers about the presence of the observed gaps, the interview process would continue by pointing out to the teacher that she had encountered a gap (whether she initially recognized it or not) and then asking her to share what she was thinking at the time that may have influenced whether or not she recognized the gap in her knowledge. This line of questioning, though more direct and potentially prone to more influence from researchers, has the potential to provide data that will better address the issue of why teachers recognize their science content knowledge gaps and what relationships between teacher cognition and potential trigger events have the potential to activate these triggers for learning.

Along these same lines, a continued focus on the model for teacher learning from practice (Figure 1.1) is another reasonable next step for future research. Because this research focused only on what gaps teachers encountered in the classroom, the nature of the triggers and indicators of those gaps, and whether the teachers recognized the gaps, one of the next steps in this research agenda is to conduct research on the degree and accuracy of the learning that takes place when teachers recognize and attempt to bridge the gaps in their own science content knowledge and what sources teachers turn to as they attempt to bridge their science content knowledge gaps. There are, however, some specific questions related to teachers' confidence and levels of daily preparation to teach that arose during the course of this study, which will also require additional future research to address.

Interrelationships among confidence, daily preparation to teach, and gaps. It was evident from the analysis in Chapter 5 that the teachers' expressed confidence levels and levels of daily preparation to teach were interrelated, influencing one another as well as the number of gaps teachers encountered. One of the challenges faced during data analysis was that the important relationships among expressed confidence, daily preparation, and gaps only became clear after all of the data had been collected and was already being analyzed. Consequently, the operationalized definitions for level of daily preparation to teach were relatively subjective in this study (partly because they were based on data collected prior to the decision to define preparedness). This level of subjectivity was effective in pointing out that there were relationships between confidence and preparation that seemed to affect the numbers of science content knowledge gaps the teachers encountered during instruction. The data in the current study, however, could not adequately address more specific explanations of these relationships and their interconnectedness.

Additionally, Because I asked teachers how confident they were with their knowledge of the subjects they were teaching after they had taught their first class that day, it was impossible to know how the teaching process had influenced their confidence. For example, it seemed that Ms. Keller's expressed confidence level might have been higher if she had been asked question about confidence before she taught the first lesson I observed. She had read through the book and put together a PowerPoint presentation for her students to take notes on after they watched a video, so she had obviously prepared for class that day. It was clear, however, that it was only after she had started to go through the PowerPoint presentation with her first class that she fully realized how much she still needed to understand about the topic of the different types of energy before she could teach it effectively. I felt her confidence decreased during the course of the lesson she was teaching, but there was no way to determine that beyond speculation.

Likewise, at the other end of the spectrum, Ms. Lane's descriptions of her daily preparations to teach were very detailed and seemed to indicate that she was much less confident in her knowledge of the subject matter she was teaching before she had taken the extensive time to prepare for each day of instruction. On the other hand, Ms. Kidd seemed to indicate that she was fairly confident before preparing to teach because she felt like she already had a good background in the science content. Both Ms. Lane and Ms. Kidd expressed high levels of confidence, were adequately prepared to teach, and encountered relatively few gaps during instruction. It is interesting, however, to note that Ms. Lane's high confidence and low gaps were likely influenced by her extensive preparation through which she likely increased her confidence and encountered her gaps before entering the classroom. In contrast, Ms. Kidd's high confidence and low gaps were probably much less specifically related to or affected by her preparation to teach the observed lessons. Additionally, it seems reasonable to assume that, depending on their prior knowledge of concepts or topics, these scenarios could have been flipped with each of these teachers for a given instructional day.

These three examples suggest fluidity in the construct of teachers' confidence in their knowledge. This confidence, which plays a role in learning from practice, may change (slightly or dramatically) over a short period of time, and these changes can potentially influence teachers' abilities to learn from their own teaching practice. Additional research would be helpful to address questions related to how daily preparation and teaching can both influence teachers' confidence in their science content knowledge for the subjects they are teaching. This research could include more objectively defined and measurable rankings for teachers' levels of daily preparedness to teach as well as their expressed confidence. Additionally, rather than asking teachers about their confidence only after they have taught, future research would ask about their confidence (using a Lichert scale) before preparing to teach, immediately before teaching, immediately after teaching, and a number of days after teaching. Combined with classroom observations and follow-up interviews similar to the present study, this additional data could lead to a better understanding of the interrelationships among prior knowledge, daily preparation to teach, teacher confidence, and learning from practice.

Influences of professional development on daily preparation to teach. Another unexpected but very interesting issue related to teachers' daily preparation to teach and expressed confidence involved Ms. Beam's and Ms. Ardis's relative lack of personal prior preparation to teach lessons for which they had attended professional development seminars. As noted above, based on their interview responses, both teachers were probably more confident in their knowledge of the inquiry activities than the observations would indicate they should have been. This leads to questions about the overall effectiveness of professional development workshops and what ways professional development might be changed for maximum effectiveness, especially relating to how much time teachers need to spend at the workshops and actually spend preparing to teach these lessons on their own.

Often professional development workshops are designed to cover a significant amount of material in a short period of time. In this way, the workshops usually necessarily omit large amounts of information that it is expected the teacher will read or study on their own. The goal of the workshop is often to get teachers familiar with the lesson or unit and to be able to see how to set up inquiry apparatuses and go through the procedures of some of the activities. Although it was not expected, it also was not altogether surprising that Ms. Beam assumed that attending the professional development workshop was enough preparation to teach the battery inquiry lesson to her class. This assumption was supported by the fact that she opened the seal on the bottle of copper sulfate powder (a necessary ingredient for the activity) in class with her students. Granted, these may have been relatively isolated incidents, but the fact that two different teachers in this study similarly spent less time preparing to teach because they attended professional development seminars does not seem coincidental. Consequently, the following questions seem important to address: (a) Does attending face-to-face professional development seminars for particular inquiry lesson(s) similarly influence other teachers to spend inadequate time on their own preparing for the same lesson(s)?; (b) If so, are there ways to change the way professional development is designed and carried out to maximize the opportunities for teachers to get the support they need while still spending adequate time personally preparing to teach?; and (c) Will teachers with no professional development for any given lesson(s) implement the lesson(s) any better or worse than teachers who received professional development support?

One possible suggestion for studying these questions in relation to the influences of professional development on teachers' daily preparation to teach would involve researching a group of teachers who will be teaching the same kit-based inquiry lesson(s). The research would commence by randomly assigning the teachers to one of three experimental conditions: (a) teachers attend a normal face to face professional development seminar; (b) teachers prepare for the lesson(s) on their own with an online manual that includes hyperlinks to video clips (e.g., how to set up an apparatus used in the lesson or how to go through specific procedures for certain inquiry activities); and (c) teachers are provided with paper manuals for the inquiry lesson(s) so they can prepare for the activities on their own without additional outside help.

The research would also include observations, surveys, and interviews to determine the ways in which the different experimental conditions may influence the effectiveness of the each teacher's preparation to teach the lesson on her own as well as how the different possible relationships between professional development and personal preparation to teach can influence the gaps teachers encounter in during classroom instruction, whether the teachers recognize those gaps, and whether the teachers adequately bridge the gaps they encounter.

Conclusion

Learning science content through teaching practice is an essential element in the professional progression of middle-school science teachers, and one of the greatest challenges of learning from teaching practice is for teachers to recognize when they do not know something or when they may have unrecognized misconceptions. As teachers transition from preservice to early-career teachers they have to navigate a gauntlet of challenges with regard to their pedagogy, their science content knowledge, and the contexts in which they teach. The findings of this research have the potential to provide teachers with tools for learning from practice leading to early opportunities to engage in reflective teaching practice as they navigate the other challenges of being a new teacher. These tools and practices can potentially help teachers better learn from their teaching practice as they engage in and promote behaviors in the classroom that are conducive to learning from practice. Although the current research does not address the cognitive and metacognitive aspects of what occurs when teachers encounter gaps in their science content knowledge (something that will hopefully be addressed in future research) this research does detail observable events or behaviors in the classroom that can be utilized in reflective practice as potential indicators of science content knowledge gaps. The hope is that understanding and paying attention to these outward indicators can help teachers better recognize and understand the thought processes they go through as they are encountering gaps in their knowledge.

In general, learning from practice is a necessity, especially because there are often large gaps between what preservice teachers learn in their post-secondary education and what practicing teachers need to know to teach science effectively in the classroom. Eventually, teachers will develop skills to learn from practice just by being in the classroom long enough.

This research, however, has the potential to provide teachers with insights that may allow them to jumpstart the processes and practices of learning from their own teaching practice earlier in their careers. As one of the teachers in this study said, “Obviously teaching… deepens your understanding of [concepts] at a basic level.” Similarly, when I asked another teacher why she felt like she had a better understanding of a scientific concept we talked about in the interview, she said, “Because I had to learn how to teach it.”

This research does not address a new phenomenon. I often hear teachers say they never really understood a certain concept or field of study until they had to teach it. I have had similar experiences in my own teaching practice. This research does, however, attempt to develop a better understanding of the processes of learning from teaching practice, particularly in relation to the gaps teachers encounter during classroom instruction, what classroom events seem to illuminate, trigger, or indicate those gaps, whether and when teachers recognize these gaps in their knowledge, and what teachers can do to help promote learning from their own teaching practice (particularly in relation to encountering, recognizing, and addressing gaps). By developing a better understanding of these phenomena, this research has the potential to influence how teacher educators, teacher induction providers, and teacher professional development providers teach teachers about how to learn from their own teaching practice. Additionally, as teachers become aware of this information (either on their own or from individuals who help facilitate their learning experiences) they have the potential to improve the ways in which they learn from their own practice which can potentially improve their teaching practice and effectiveness overall.

APPENDICES

APPENDIX A

Observation Protocol

Observation protocols focus on looking for indicators of gaps in the teacher's content knowledge as well as the potential learning triggers that acted as the catalyst for those indicators. The potential gap indicators observed in the classroom and interview responses and the potential learning triggers come from my previous pilot study (Kinghorn, 2008) and from a study of early-career secondary science and mathematics teachers across the nation (see Kinghorn & Britton, 2012; Putnam, Britton, & Otten, 2009).

Video-taped classroom observations of early-career middle school science teachers will be the main site for identifying instances when there may be potential gaps in a teacher's science content knowledge. This process will include identifying any instances where the teacher may be encountering something new; identifying potential triggering events in the classroom (based on my list of these events from the preliminary study listed below) and determining whether the nature of the event (e.g. student question) had the potential to identify a gap in the teacher's science content knowledge; observing teachers' reactions and responses to potential triggering events that may better indicate the teacher is being faced with something new; and observing similar behaviors or reactions exhibited by the teacher that may not be associated with one of the previously identified triggering events. Based on my observations, I will determine which of these classroom events seems most likely to be an indication that there were gaps in the teacher's science content knowledge. Follow-up interviews will include viewing video clips of these events with the teacher. Because of time constraints, only the most salient of these events or situations will be discussed in the follow-up interview.

Definition of Terms

Potential Learning Trigger: An event or situation that has the potential to illuminate or identify a gap in a teacher's content knowledge and potentially trigger learning new content knowledge.

Potential Gap Indicator: Observable behavior (from the teacher or students) or event that suggests possible gaps in the teacher's content knowledge.

The potential trigger can act as a catalyst that identifies a potential gap in the teacher's science content knowledge and how the teacher reacts is a behavioral response to that catalyst (whether or not the teacher recognizes the content knowledge gap). If there is an observable indicator that there may be a gap in the teacher's content knowledge, it is more likely that the event/situation that triggered/caused the behavior will be a learning trigger. Every single student question or response etc. could be a potential trigger. However, if a student asks a simple question or gives an acceptable response that the teacher was expecting, the question or response is less likely to act as a trigger and would be less important to focus on. Looking for behavioral responses to potential triggers and identifying the trigger based on the response will give me a better idea of what events/situations in the classroom had the potential to act as learning triggers (ie they illuminated a potential gap—whether or not the teacher recognized it—in the teacher's content knowledge.)

Potential Learning Triggers (from Kinghorn, 2008)

1. Anticipating teaching new material

    a. Teaching something never learned and/or taught before

    b. Feel obligation to "get it right" for students—motivating factor

    c. Specific assignment to teach science—motivating factor

2. Recognizing inadequacies in curriculum materials

3. Classroom Discourse

    a. Student questions

    b. Student ideas/comments

    c. Student answers/responses

    d. Student research

4. Reflection on or in practice

    a. Reflecting-in-action ah-ha/eureka moments

    b. Teacher makes a content error (whether recognized or not)

    c. Lesson or experiment does not go as expected

        i. Students do not seem to “get it”

        ii. Results of an experiment/demo are different than they “should be”

Observable Classroom Potential Gap Indicators

Responses to Student Input:

Teacher fails to respond or respond adequately

-- Teacher does not acknowledge or respond to a student question or comment.

--Teacher acknowledges a student question or comment but does not address it.

Example: saying “that’s nice” and moving on.

--Teacher states that they do not know the answer to a student question or states that something a student says is something they do not know or cannot confirm.

--Teacher only briefly addresses (in the researcher's opinion they do not adequately provide an entirely content appropriate response) a student question or comment.

Teacher response includes "looking up" or finding the "correct response"

--In response to a student's question, comment or idea the teacher goes to (or takes the class to) the textbook/curriculum or another source (Internet, book, other teacher, etc.) to find the answer.

--In response to a student's question, comment or idea the teacher gives the student a homework assignment to find the answer and then report it to the rest of the class at a later time.

--In response to a student's comment or idea, the teacher asks the student where they got/learned that information.

Teacher fails to recognize potentially correct or incorrect student responses

--A student provides a plausibly correct response to a question which the teacher dismisses as incorrect because it was not the response the teacher was "looking for." (Example: moon phases—teacher wants response of 8 phases but student says there could be 31 phases (one for each day of the month))

--Teacher does not address obvious discrepancies between student responses/answers/results that are a clear indicator that some students may not understand the scientific concepts.

--Student content errors. Unless a teacher clearly correctly corrects the error or helps the student correctly correct it, every student error is an indicator of a potential gap in content knowledge. (Example: when testing substances for pH one student says a substance is a base and another student calls the same substance an acid.)

Unplanned Outcomes

--It is clear that many of the students do not understand the concepts the teacher has explained or the way the teacher has explained it (whether or not the teacher recognizes this).

--As a result of a student question or response the teacher clearly alters/rearranges the planned lesson to accommodate or more fully explain that conceptual issue.

--Teacher makes a noticeable pause (assumedly to think/mentally regroup thoughts) before responding to a student question or comment or moving forward in the lesson. (Example: An observer may say "I wonder what the teacher is thinking about right now")

Teacher's delivery/presentation/explanation of lesson/content:

Teacher Content Errors/Discrepancies

--Teacher explains a concept or process incorrectly (content error) while teaching the class. (Unfortunately, while this does indicate a gap in the teacher's content knowledge, the situation can rarely trigger learning because there are few ways for the teacher to realize they lack conceptual understanding on their own.)

--Teacher gives information to the students in one way and later explains the same concept(s) in a different way.

Unplanned Outcomes

--The teacher indicates that an in-class demonstration or experiment did not go the way the teacher expected it to go. (Example: a chemical reaction that is supposed turn green turns yellow instead.)

--Teacher makes a noticeable pause (assumedly to think/mentally regroup thoughts) before responding to a student question or comment or moving forward in the lesson. (Example: An observer may say "I wonder what the teacher is thinking about right now")

-- The teacher noticeably changes the direction of the lesson (whether indicated by the teacher or seemingly obvious to the researcher) from its original trajectory.

Interview Response Potential Gap Indicators

Indicators related to preparing to teach

--Teacher indicates that their curriculum is inadequate for their needs. (The *recognition* of the inadequacy, not the inadequacy itself, is the illuminates the potential gap in content knowledge)

--Teacher indicates that they recognize their preservice training was inadequate for their current content needs teaching science. (Again, the *recognition* is the potential trigger here)

--Teacher talks about anticipating teaching something new.

--Teacher indicates that they taught something they had never learned before. (anticipating teaching something new)

--Teacher indicates that they taught something that they had never taught before. (anticipating teaching something new.)

--Teacher expresses a strong desire to get the science content "right" for their students.

Indicators related to classroom practice

-- Teacher mentions anything from the observed lesson or from other teaching experiences that indicate they recognized gaps in their content knowledge or learned something new.

Indicators related to reflecting on practice

-- Teacher talks about sources (other teachers, Internet, books, etc.) they have gone to or plan to go to for the purpose of learning something new or bridging a perceived gap in their content knowledge.

-- Teacher mentions any aha/eureka moments they have had while teaching

Errors in the interview

-- Teacher makes a content error in the process of the interview

Reflection during interview

--During interview (watching video clip or talking about what happened in class) the teacher mentions that he/she did not recognize a gap in their knowledge at the time but as they look back they recognize it. (This will be determined by a follow-up question about when they had the realization of the content knowledge gap if they indicate there was one)

APPENDIX B

Follow-up Interview Protocol

Preliminary Questions for first Interview

Introductory Information

-- How long have you been teaching and what grades have you taught?

-- Do you have a secondary, elementary or 'other' teaching credential? Please explain.

What science courses did you take in college?

-- What science subjects have you taught? What are you teaching now?

-- What kinds of things do you find most rewarding or enjoyable about teaching science?

-- What kinds of things do you find most frustrating about teaching science?

-- What are your feelings about teaching science?

General questions about teaching practice:

-- What do you do if/when your students have questions about the science content that you don't know?

-- What different strategies might you use in cases like these?

-- What do normally do if/when you've explained a science concept to your students and they don't seem to understand it?

-- In what ways do you find your science curriculum helpful or lacking?

How helpful is it for you?

-- What do you normally do when you have finished a lesson that went particularly well?

-- How about lessons that went horribly?

-- Do you ever use the Internet to learn new science ideas?

-- How do you prepare for teaching?

-- What sources to you turn to for support?

-- What do you do when you realize you don't know something you need to know?

Preliminary Questions Addressed in Second Interview

-- How adequate was your preservice training for what you are teaching now?

Please elaborate.

-- How adequate is your curriculum for what you are teaching now?

-- In what ways, if any, is your curriculum lacking?

-- What do you do when you are preparing to teach something you have never taught before?

-- Have you ever thought something was one way and the key or textbook said it was another

What did you do?

Was the textbook correct or incorrect?

-- Have you ever had to teach something you either never learned before or forgot that you had ever learned?

Can you give me any examples?

How did/do you approach situations like these?

-- Have you ever started confidently preparing a lesson and then realized you did not know the content as well as you thought you did?

Can you give any examples?

How did you respond to these situations?

-- What motivates you to get the content you are teaching correct?

-- How do you approach student input (ideas, comments, suggestions, answers) in the classroom?

-- Do you ever realize you do not know something and/or learned something new as a result of student input in the classroom? If so, could you please elaborate?

-- What do you normally do when a student gives you an answer that is not what you were looking for?

-- Has a student ever given you an answer that you thought was wrong but later realized it could be an acceptable answer? If so please elaborate.

-- Do you ever have experiences in the classroom that help you better understand how your students think and process information? Examples?

Have you noticed any typical student misconceptions?

-- Have you ever said something incorrectly in class and later realized you were wrong? Please elaborate.

How do you generally approach these types of situations?

-- What do you do when your students do not seem to “get it”? Examples?

-- What do you generally do when an experiment or classroom demonstration does not go as planned or expected? Please elaborate.

-- Have you ever had any aha moments while teaching when something just clicks and makes sense? Please elaborate.

General Overview Questions about the Observed Classes

For all of the questions in the interview, ask appropriate follow-up questions to get more information.

Thanks for letting me visit your class today. I really appreciate you taking the time out of your busy schedule to visit with me.

--How did you feel about today's lesson(s)?

--Did things go as expected or were there some aspects of the lesson(s) that were a surprise to you? Please elaborate.

--How confident were you about your knowledge of the science content in the lesson(s) you taught today?

--In what ways did that confidence (or lack of confidence) affect your preparation to teach the lesson(s).

--How did your confidence level affect the lesson itself?

--Were there any instances while you were preparing to teach, teaching today, or thinking about your teaching where you felt like you encountered something new? If so, please elaborate.

Reflection on previous lessons

--In what ways did yesterday's lessons influence how you prepared for and taught the lessons today? Please elaborate.

<u>[After the first follow-up interview]</u>

--Did you have any opportunities to reflect on the lessons you taught the last time I visited you? If so could you please tell me about your reflection and the outcomes?

Questions about Preparing to Teach

--Giving as much detail as possible would you please walk me through your preparation for today's lesson(s)?

--How did you utilize the curriculum materials as you prepared for today?

--What were your feelings about the curriculum you used. Please be as detailed as possible and talk about any pros and cons with regard to the curriculum materials you used.

--Did you use any sources that were not in the curriculum in preparing for today's lesson(s)? If so please tell me about those sources, why you chose to use them and how useful they were for you.

--Did you use any online resources to help you prepare for the lesson(s)? Why or why not? Also please elaborate on what resources you used and walk me through how you used them.

--Did you talk to anyone about the lesson before you taught it? If so who, and why? What did you talk about? Was it helpful? Please elaborate.

Reflecting on/in today's lesson

--Did you have a chance to reflect on anything you taught during lunch, between classes, or during your prep period? If so, please tell me about it.

<u>Aha moments</u>

--During today's lessons did you have any aha moments today where something you were confused or perplexed about just "clicked" for you?

[I may be able to observe some moments of insight which I'll address individually. However, due to its nature there may be instances of insight that I will not notice and the only way to know about them is asking a direct question.]

Questions Related to Today's Lesson and my Observations

Prior to the interview download the observation video and watch the instances noted in the field notes to determine what clips seem most likely to indicate gaps in the teacher's science content knowledge. Prepare these clips to show the teacher. Some instances will be better with the video and others can be taken from the field notes. Some examples of questions based on field notes are listed below.

Show the teacher a clip from class.

For each of these clips ask the teacher to talk about what was going through their mind during the interchange without implying anything about what I think it meant. Rather than inserting my perceptions into the interview, I will reference the event and ask the teacher to talk me through the experience, making sure to focus on what they were thinking during the experience.

<u>If the teacher clearly explains the situation so it is clear that there was not a gap in their science content knowledge:</u>

--Move on to the next video clip or question.

<u>If the teacher recognizes and points that they had encountered something new or that there was a gap in their knowledge:</u>

--When did you realize that this was something new?. (immediately, later in the class, as you watched the video clip)

--What were your feelings before and after the event (triggering event) that indicated to you the gap in your knowledge?

<u>Examples of field note questions</u>

1. In second period today when you were asking the students to tell you about _________, one of your students said __________. You pointed out that their response was incorrect by saying __________. Do you remember that interchange? If so, would you please walk me through it and tell me what you were you thinking throughout the interchange.

2. I noticed at one point you said __________ to your students, but then you quickly told them it was really _________. What was going through your mind when this took place? Why did you decide that ________ was incorrect and _________ was a better way to explain the concept?

3. Today when you were asking for comments from students so and so said _________. I noticed that you paused for a few seconds before you responded to her comment. What was going through your mind during that time?

4. When you were teaching about ________ today you seemed to be floundering a bit, trying to figure out the best way to explain it to your students. Could you please give me some insight into what you were thinking.

New questions based on the interview

The interview should also be left open enough to address any other items of interest that may have arisen in the observation or during the interview.

APPENDIX C

Cohen's Kappa Calculations

Total Gaps

Pa= 55/66 = .833

Pe=

Prob yes =BK 56/66 x BF 59/66= BK.848 x BF.894 = .758

Prob no= BK12/66 x BF 7/56= BK.182 x BF.125 = .023

.758 + 0.023 = .781

(.833 -.781)/(1-.781) = .052/.219 = .237

Number of SMK Gaps

Pa= 41/51= .804

Pe=

Prob yes= BK 29/51 x BF 27/51 = BK .568 x BF .529 = .300

Prob No= BK 22/51 x BF 24/51 = BK .431 x BF .471 = .249

.249 + .300 = .549

(.804 - .549)/(1 - .549) = .255/.451 = .565

Number of PCK Gaps

Pa= 47/51 = .922

Pe=

Prob yes= BK 33/51 x BF 35/51 = BK .647 x BF .686 = .444

Prob no= BK 18/51 x 16/51 = BK .353 x BF .314 = .111

.444 + .111 = .555

(.922 - .555)/ (1 - .555) = .367/.445 = .825

Recognized SMK Gaps

Pa= 21/23 = .913

Pe=

Prob yes= BK 16/23 x BF 16/23 = BK .696 x BF .696 = .484

Prob No= BK 7/23 x BF 7/23 = BK .304 x BF .304 = .092

.484 + .092 = .576

(.913 - .576)/ (1 - .576) = .337/.424 = .795

Recognized PCK Gaps

Pa= 27/31 = .871

Prob yes = BK 27/31 x BF 27/31 = BK .871 x BF .871 = .759

Prob no= BK 4/31 x BF 4/31 = BK .129 x BF .129 = .017

.759 + .017 = .776

(.871 - .776) / (1 - .776) = .095 / .224 = .424

Total Recognized Gaps

Pa=48/54 = .889

Prob yes = BK 43/54 x BF 43/54 = BK .796 x BF .796 = .634

Prob no = BK 11/54 x BF 11/54 = BK .204 x BF .204 = .042

.634 + .042 = .676

(.889 - .676) / 1 - .676) = .213 / .324 = .657

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