

EXAMINING THE PEDAGOGICAL CONTENT KNOWLEDGE AND PRACTICE OF
EXPERIENCED SECONDARY BIOLOGY TEACHERS
FOR TEACHING DIFFUSION AND OSMOSIS

A Dissertation

Presented to

the Faculty of the Graduate School

University of Missouri

In Partial Fulfillment

of the Requirements for the Degree

Doctor of Philosophy

by

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March, 2010

The undersigned, appointed by the Dean of the Graduate School have examined the dissertation entitled

EXAMINING THE PEDAGOGICAL CONTENT KNOWLEDGE AND PRACTICE OF
EXPERIENCED SECONDARY BIOLOGY TEACHERS
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A candidate for the degree of Doctor of Philosophy

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*Dedicated to my husband, John, whose love, patience, selflessness, and unending support
has made this project possible.*

ACKNOWLEDGEMENTS

This dissertation is the result of support and guidance from many very talented and knowledgeable individuals. I first want to thank my dissertation advisor, Dr. Patricia Friedrichsen, first for always challenging me to think deeply, search for explanations, and achieve more than I thought possible. Your enthusiasm, outstanding guidance, and excellent mentoring enabled me to grow as a researcher. I cannot thank you enough for so generously sharing your time, talent, and expertise.

I extend my gratitude to the members of my doctoral committee. Your comprehensive exam questions provided the basis for my research and your feedback, suggestions, and ideas guided my progress. Each of you has contributed greatly to my knowledge of education, science, and research throughout my program. I want to thank Dr. Lloyd Barrow, whose thoughtful guidance, insight, and support throughout my doctoral program has been invaluable. I want to extend my gratitude to Dr. Mark Volkmann whose research mentorship provided the foundation of knowledge and understanding of research needed to accomplish my dissertation work. Dr. David Bergin, and Dr. vom Saal, thank you for your unique insights and advice. Thank you all for the genuine concern and interest in my progress throughout my doctoral program. Your support has been an outstanding source of knowledge and strength.

I would like to thank all of the faculty members of the Science Education Center. Your knowledge and professionalism are impressive. Working with you through courses, projects, and internships has greatly enhanced and extended my knowledge and understanding of science education, teacher preparation, and education research. Thank you for having high expectations and challenging me to think deeply and achieve more. I

want to extend my gratitude to Dr. Sandra Abell for extending the opportunity to work with Missouri science teachers and university faculty through the PREP program and as the coordinator of the Exploring Life Sciences at MU Conference. Your kindness and support are greatly appreciated. Thank you to Dr. Patricia Friedrichsen, Dr. Sandra Abell, Dr. Mark Volkmann, Dr. Lloyd Barrow, Dr. Debbie Hanuscin, and Dr. Marcelle Siegel for creating such a warm and welcoming professional home for all of the graduate students. I have greatly appreciated the pot luck suppers and holiday parties you have so generously organized and supported. You invited graduate students to work with you and learn to investigate teacher learning and preparation.

I want to extend my gratitude to all of my science education colleagues for their friendship and kindness. Thank you to Aaron, Andrew, Dana, Ya-Wen, Dominike, Will, Enrique, Kristy, Pat, Michelle, Renae, and Cathy for your friendship.

Thank you to the dedicated and talented teachers who participated in my study. Your willingness to open your classroom, share your time, thoughts, knowledge and expertise were greatly appreciated. Your thoughtful explanations, knowledge of teaching, learning, and learners provided important insights into the specialized knowledge held by experienced science teachers.

Last but not least, thank you to my wonderful family. Your love and support is cherished more than you will ever know. Most of all, thank you to my wonderful husband, John. Your brilliance, work ethic, and dedication to excellence always inspired me. But most of all your love, kindness, and endless support are the very essence of my life.

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ABSTRACT

Teachers are the most important factor in student learning (National Research Council, 1996); yet little is known about the specialized knowledge held by experienced teachers. The purpose of this study was twofold: first, to make explicit the pedagogical content knowledge (PCK) for teaching diffusion and osmosis held by experienced biology teachers and, second, to reveal how topic-specific PCK informs teacher practice. The Magnusson et al. (1999) PCK model served as the theoretical framework for the study. The overarching research question was: When teaching lessons on osmosis and diffusion, how do experienced biology teachers draw upon their topic-specific pedagogical content knowledge? Data sources included observations of two consecutive lessons, three semi-structured interviews, lesson plans, and student handouts.

Data analysis indicated five of the six teachers held a constructivist orientation to science teaching and engaged students in explorations of diffusion and osmosis prior to introducing the concepts to students. Explanations for diffusion and osmosis were based upon students' observations and experiences during explorations. All six teachers used representations at the molecular, cellular, and plant organ levels to serve as foci for explorations of diffusion and osmosis. Three potential learning difficulties identified by the teachers included: (a) understanding vocabulary terms, (b) predicting the direction of

osmosis, and (c) identifying random molecular motion as the driving force for diffusion and osmosis. Participants used student predictions as formative assessments to reveal misconceptions before instruction and evaluate conceptual understanding during instruction. This study includes implications for teacher preparation, research, and policy.

CHAPTER ONE: INTRODUCTION

Achieving scientific literacy became a major goal in science education with the launch of Sputnik in 1957 (Bybee, 1997; DeBoer, 2000; Hurd, 1998). In the 1990s, “scientific literacy was the single term expressing the purposes of science education” (Bybee, 1997, p. 64). DeBoer (2000) noted the importance of science education for the general population in the United States in terms of “the public’s attitude toward science and their ability to serve as thoughtful critics of the role of science in society” (p. 584). Thus, as the world becomes increasingly reliant upon science, mathematics, and technology, there is genuine concern about the quality and effectiveness of science education in the U.S. (American Association for the Advancement of Science, 1993; Bybee, 1997; Hurd, 1998; Phillips, 2007).

When students fail to develop a basic understanding of scientific concepts and the processes and methods of science, they perceive science as separate from their lives. This is especially troubling in a world increasingly reliant upon science and technology; thus, the scientific literacy of the American populace is of great concern. According to the National Science Board (2004), the average citizen in the United States understands very little about science. The United States must significantly increase the scientific and mathematical competency among K-12 students to ensure an adult population able to understand and reach consensus on policies addressing the world’s most pressing problems (National Science Board [NSB], 2004; Phillips, 2007).

Concerns about the quality and effectiveness of science education in the United States are mounting as American youth fall behind their international peers in other nations in terms of knowledge of science and technology (Bybee, 1997; DeBoer, 1991;

DeBoer, 2000; NSB, 2004; Phillips, 2007). There is a significant body of evidence indicating American youth are ranked well below the highest achieving countries (Phillips, 2007; Trends in International Mathematics and Science Study (TIMSS), 2003, 2007). International data on students' knowledge of science collected from Trends in International Mathematics and Science Study (TIMSS) indicates that U.S. eighth-grade students' performance (see Table 1) was above the international average for both the 2003 and 2007 TIMSS (National Center for Educational Statistics [NCES] 2003; 2007); however, this picture is not as bright as it seems.

Table 1^{1,2}. *U.S. fourth and eighth graders performance in science on the 2003 and 2007 TIMSS*

2003 Results	2007 Results
Eighth grade	Eighth grade
U.S. eighth grade students scored 527, on average, exceeding the international average of 473.	U.S. eighth-graders scored 520, on average, in science, which was higher than the TIMSS scale average of 500.
The average eighth-grade science scores exceeded eighth-grade science scores in 32 countries, fell below that of 6 countries (Asian and European), and was not measurably different from scores in 5 countries.	The average U.S. eighth-grade science score exceeded that of science scores in 35 countries, was lower in 9 other countries (Asian and European) and not measurably different from 3 countries.

It is important to note that in 2003, eighth graders in the United States scored above the international average in science achievement by an average of 54 points (NCES, 2003); while in 2007 eighth graders in the United States were only able to maintain an average lead of 20 points above the international average score for science (NCES, 2007). Another concerning statistic is that U.S. eighth graders were outperformed by their peers in five other countries in 2003; while in 2007, U.S. eighth

¹Note: From "Highlights from the Trends in International Mathematics and Science Study (TIMSS) 2003." By National center for Educational Statistics (2005). Washington D.C.: Retrieved on August 10, 2009 from <http://nces.ed.gov/pubs2005/timss03/science1.asp>

²Note: From "Highlights from TIMSS 2007: Mathematics and Science Achievement of U.S. Fourth- and Eighth-Grade Students in an International Context." By National Center for Educational Statistics. Washington D.C.: Retrieved on August 10, 2009 from <http://nces.ed.gov/pubs2005/timss03/science1/asp>

graders fell below nine other countries (NCES, 2003, 2007). Overall, the U.S. performance in science was significantly lower than that of many Asian and European countries including Singapore, Republic of Korea, Hong Kong, Taipei, Japan, Netherlands, Hungary, and the Flemish portion of Belgium.

Another significant concern is the low number of U.S. youth preparing for careers in science, technology, engineering, and mathematics (STEM); only 16 percent of all postsecondary degrees in the United States are related to STEM fields and many of these postsecondary degrees are awarded to foreign students (Phillips, 2007). Linda Froschauer, former president of the National Science Teachers Association (NSTA), reported the number of engineering degrees awarded in the United States has decreased by 20 percent from 1985. South Korea, a nation with approximately one-sixth of the U.S. population, graduates as many engineers as the United States. This is a disturbing trend as 15 of the 20 fastest growing occupations projected for 2014 require significant science and mathematics knowledge (Froschauer, 2006).

Students develop their attitudes toward science and their understanding of science throughout their K-12 educational experiences. Therefore, teachers are a critical factor in student learning (Committee on Science and Mathematics Teacher Preparation [CSMTP], 2001; King & Newman, 2000). Teachers control the learning environment and ultimately determine what is taught, when it is taught, and how it is taught (Abell, 2007; CSMTP, 2001; King & Newman, 2000). To be successful, teachers must have strong subject matter knowledge, understand the nature of science, be able to translate scientific concepts into meaningful learning experiences for their students, and highlight

applications for science within society and in the lives of students (Gess-Newsome, 1999).

The *National Science Education Standards* (NRC, 1996) describes effective science learning as occurring when learners are actively engaged in science; making connections between scientific concepts; applying their knowledge of science to problem solving; supporting claims with evidence; and reflecting upon their methods, processes, and conclusions. This description of science learning requires that science teachers have a deep and flexible understanding of science subject matter and scientific concepts, as well as an understanding of students as learners, knowledge of instructional strategies, representations, assessment strategies, and curricular resources (Darling-Hammond, 2008).

Schwab (1971) described teacher knowledge in practical terms as the wisdom of practice developed through classroom experience. Feiman-Nemser (2001) notes that knowledge for teaching develops with experience as teachers learn to blend their knowledge of students as learners with their knowledge of content to make concepts understandable. Verloop, Van Driel, and Meijers (2001) posit teacher knowledge is closely related to individual experiences and contexts and, therefore, unique to the individual. Successful teachers are able to transform their knowledge of scientific concepts into a form of knowledge that can be understood by learners by integrating their knowledge of learners, representations, instructional strategies, assessments, and curricular resources to create meaningful learning opportunities that make connections between lesson content and students' experiences (Shulman, 1987). To be effective, teachers need to (a) activate prior knowledge, (b) predict student difficulty with content,

(c) adjust teaching approaches and strategies to better address diverse student learning needs, (e) make connections between concepts, (f) identify relevant connections between content and student lives, (g) provide opportunities for students to assess their learning, (h) use feedback on formative assessments to inform instruction, and (i) align instructional goals and methods with the topics being taught (Barnett & Hodson, 2001; Doyle, 1985; Lee, Brown, Luft, & Roehrig, 2007; Lee & Luft, 2006; Magnusson et al. 1999; Treagust, 1987; van Driel, Verloop, & de Vos, 1998).

Shulman (1987) identified pedagogical content knowledge (PCK) as a unique form of knowledge expressly for teaching. He described PCK as including subject matter knowledge, knowledge of potential student learning difficulties and students' prior knowledge for specific concepts, as well as the most effective models, analogies, illustrations, explanations, and investigations to make the concept understandable for students. "In a word, the ways of representing and formulating the subject that make it comprehensible to others" (Shulman, 1986, p. 9).

Grossman (1990) expanded upon Shulman's (1986) ideas to emphasize four general areas of teacher knowledge including: subject matter knowledge; general pedagogical knowledge; knowledge of context; and the core of Grossman's model, pedagogical content knowledge (PCK). Grossman (1990) defined PCK as consisting of four components: (1) knowledge and beliefs about the purposes and goals for teaching science, (2) knowledge of students' understanding of science, (3) knowledge of science curricula and curricular resources, and (4) knowledge of representations and instructional strategies.

Magnusson, Krajcik, and Borko (1999) build upon the work of Grossman (1990) to conceptualize pedagogical content knowledge (PCK) as consisting of five components: (1) teacher orientation for science teaching, (2) knowledge of students understanding of science, (3) knowledge of representations and instructional strategies, (4) knowledge of assessment, and (5) knowledge of curriculum (p. 96). Topic-specific PCK is described by Magnusson et al. (1999) as the knowledge representations and instructional strategies useful for teaching a specific topic in science, the knowledge of potential student learning difficulties and prior knowledge associated with the topic, knowledge of the most effective assessment strategies to reveal students' understanding of the topic, as well as knowledge of the science curriculum and curricular resources. Thus, PCK necessary for teaching specific topics in science would be unique to that topic.

Abell (2008) conceptualizes PCK to include four important characteristics: (1) PCK includes discrete categories of knowledge applied synergistically during teaching, (2) PCK is dynamic and continually changing as teachers gain teaching experience, (3) knowledge of subject matter is central to PCK, and (4) PCK supports the transformation of subject matter knowledge into a form of knowledge understandable for students. PCK is not only about knowledge the teacher possesses it is also highly reflective of the quality of teacher knowledge, teaching experience, and the manner in which the components of PCK are integrated to create effective learning experiences (Abell, 2008).

Rationale for the Study

Reform-minded science teachers actively engage students in a way that prepares students to: apply scientific principles and processes to decision making; understand the natural world; and consider careers in science, technology, engineering, or mathematics

(NRC, 1996; Texley & Wild, 2004). In her chapter on science teacher knowledge, Abell (2006) noted that “understanding the development of teacher subject matter knowledge and PCK is critical for our success in science teacher education” (p. 1133). Historically, it has been the role of science teacher educators to provide insight into the what, why, and how of teaching for prospective and novice teachers (DeBoer, 2000). In order to understand the knowledge needed for teaching, it is important to investigate the nature of PCK held by experienced teachers and how that knowledge informs their teaching.

What is largely missing from the literature is research into the knowledge and beliefs held by experienced teachers and how their beliefs about teaching and learning, and their knowledge of learners, instructional strategies and representations, curriculum, and assessment are drawn upon during teaching and reflecting. Examining experienced teachers’ knowledge for teaching can inform the design of teacher education programs. A deeper understanding of the knowledge experienced teachers draw upon when teaching and planning provides important insight for science teacher educators as they define goals and design programs and coursework for prospective teachers (Abell, 2008). Learning to teach does not mean learning to survive within the classroom; it means learning to systematically organize knowledge so that it can be drawn upon and applied to new situations (Berliner, 2001). Unfortunately, experienced teacher knowledge is not well documented. Loughran, Berry and Mulhall (2006) noted: “A real and serious issue in teaching is the ability to capture, portray and share knowledge of practice in ways that are articulable and meaningful to others” (p. 15).

Capturing and portraying the PCK of experienced science teachers takes on greater urgency due to the current shortage of qualified and certified science teachers. In

response to this shortage, many colleges and universities have established alternative certification programs (ACP) designed to prepare post baccalaureate individuals for a career as science teachers (Feistritzer, 2005; Ingersoll, 2006; Johnson, Birkeland, & Peske, 2003). Research on alternative teacher certification programs (ACP) identifies the internship and mentor teacher as one of the most influential and meaningful aspects of teacher preparation (Darling-Hammond, 2000). The mentor teacher plays a key role by modeling accurate and effective representations and instructional strategies, providing opportunities for the prospective teacher to engage students in learning activities, and socializing the prospective teacher within the professional teaching community (Darling-Hammond, 2000). Therefore, it is critical to understand the knowledge for teaching held by experienced teachers serving as mentors.

Teaching is a complex and uncertain enterprise; teachers are required to continually adjust their instructional strategies and representations to ensure student learning and effectively meet student needs (Barnett, & Hodson, 2001; Park & Oliver, 2008b). Clearly, no simple set of instructions exists to inform and prepare prospective teachers for the challenges of planning and teaching (Barnett, & Hodson, 2001). Models of successful teaching practice have the greatest potential to inform teacher preparation programs; such models can be developed by investigating and analyzing the practice of experienced teachers (Barnett, & Hodson, 2001; NRC, 1997; Sternberg & Horvath, 1995). Constructing an understanding of the nature of teacher knowledge and how components of teacher knowledge are drawn upon when teaching can only be accomplished through an investigation of experienced teachers (Westerman, 1991; Berliner, 1986; Shulman, 1986).

Prospective teachers lack specialized knowledge for teaching (Grossman, 1990; Magnusson, Krajcik, & Borko, 1999; Shulman, 1987) and, as a result, rely upon their own experiences as learners during planning and teaching. The role of the mentor teacher is to reveal prospective teacher's thinking and stimulate critical analysis of their ideas about teaching, learning, and learners; ultimately making connections between lesson content, appropriate representations, instructional strategies, curricular sequence, and assessment (Siebert, Clark, Kilbridge, & Peterson, 2006; Stanulis & Russell, 2000). Siebert et al. (2006) posit effective mentor teachers implement strategies to reveal prospective teacher's conceptions of teaching, learning, and learners and to identify and address potential difficulties with learning to teach.

The overarching goal of this study is to investigate the topic-specific PCK held by experienced biology teachers serving as mentors for prospective teachers in an Alternative Certification Program (ACP) during a year-long mentored internship. I selected osmosis and diffusion as the lesson topic for all study participants for several reasons. First, diffusion and osmosis are key concepts within biology and essential processes within all living cells. Second, high school students often find diffusion and osmosis to be challenging concepts because an understanding of these concepts requires a basic understanding and application of concepts in physics, chemistry, and biology (Odom & Barrow, 2007). To develop a conceptual understanding of diffusion and osmosis, students must visualize the movement of individual particles and predict the direction of movement at the cellular level (Friedrichsen & Pallant, 2007). Third, diffusion and osmosis are challenging topics for high school students; therefore, these concepts will also be challenging topics for teachers. Examining the practice of

experienced teachers while teaching diffusion and osmosis will reveal the nature of teacher topic-specific PCK and how their PCK informs their teaching.

Research Questions

This study addressed the central research question: “When teaching lessons on osmosis and diffusion, how do experienced biology teachers draw upon their topic-specific pedagogical content knowledge?”

Sub-Research Questions

There are a number of sub-questions that arise from the central research question. The sub-questions which guided the study are:

1. What are the nature and sources of the experienced biology teachers’ orientation to science teaching?
2. What is the nature of experienced biology teachers’ knowledge of representations and instructional strategies and how does this knowledge inform their teaching practice?
3. What is the nature of experienced biology teachers’ knowledge of students’ understanding of science and how does this knowledge of science learners inform their teaching practice?
4. What is the nature of experienced biology teachers’ knowledge of formative assessment strategies and how does this knowledge inform their teaching practice?
5. What is the nature of experienced biology teachers’ knowledge of biology curriculum and how does this knowledge inform their teaching practice?

6. In what ways do experienced teachers integrate the topic-specific components of their pedagogical content knowledge when teaching osmosis and diffusion?

Theoretical Framework

Teachers differ from content experts, such as scientists, not in terms of their content knowledge but by the way in which teachers transform their content knowledge to support their teaching and make complex and abstract concepts understandable for students (Cochran, 1997). This transformation of knowledge results from the integration of the various components of PCK to generate representations and design instructional strategies to engage students and make concepts understandable for students. Teachers must also implement assessment strategies that will effectively gauge students' understanding, encourage students' reflection, and inform next steps in teaching. When teaching concepts such as osmosis and diffusion the representations, instructional strategies, and assessments are designed specifically for that content and are, therefore, topic-specific. However, the knowledge required to teach these concepts relies upon more than knowledge of content and topic-specific representations, instructional strategies, and assessments; teachers must also understand students as learners and be aware of students' misconceptions and potential learning difficulties associated with content. Thus, PCK is a necessary knowledge base for effective teaching (Park & Oliver, 2007). The National Board for Professional Teaching Standards (NBPTS) stresses the importance of PCK within the five core propositions defining what teachers should know and be able to do (NBPTS, 2004). Teaching for understanding is enhanced with classroom experience and displayed through connections made by the teacher between the prior knowledge, experience of learners, and lesson content (Berliner, 1988). PCK is not easily revealed it

is an internal construct through which teachers codify their knowledge of content, students, instructional strategies, assessment, and curriculum into a retrievable form of knowledge for application to new challenges (Loughran, Mulhall, & Berry, 2004). In the following section I describe the components of teacher knowledge and concepts related to osmosis and diffusion.

Knowledge for Teaching Held by Experienced Teachers

A recurrent theme in education literature is that the specialized knowledge teachers acquire through classroom practice is similar to the unique knowledge acquired through other practice driven professions such as medicine or law (Lee & Luft, 2007). The unique knowledge base that teachers possess is developed through classroom experience and allows teachers to engage in pedagogical reasoning and decision making during planning and instruction to promote and support student learning (Lee, Brown, Luft, & Roehrig, 2007; Lee & Luft, 2006; Shkedi & Laron, 2004; Van Driel, et al. 1998). Barnett and Hodson (2001) characterize teacher knowledge as originating from both internal and external sources: internal sources include reflections upon experiences with students, parents, and colleagues; external sources include subject matter knowledge and contextual knowledge of the district, school, as well as, state and national standards.

Teacher knowledge is not a solitary construct which resides only within the individual but tends to be acquired and developed through professional socialization (Barnett & Hodson, 2001; Loughran et al. 2006). In essence, teachers form a ‘collective knowledge’ developed through discussions of experiences, problems, and solutions taking place during professional development opportunities, at teacher meetings, in the plan room, and in the hallway (Barnett & Hodson, 2001). Shubert (1992) described this

collective knowledge of teaching as teacher lore. Teachers construct new knowledge that is based upon their understanding of teaching, experiences in the classroom, and identify what does and does not work (Schwarz & Alberts, 1998). Good teachers have a strong subject matter knowledge coupled with an understanding of their students and effective representations and instructional strategies. Schwarz and Alberts (1998) posit that teachers continue to learn on the job with their knowledge grounded in daily experience. Collaboration with peers motivates teacher growth by maintaining a focus on teaching practice, students' learning, and content knowledge as experiences are shared with colleagues (Schwarz & Alberts, 1998).

Teacher education programs such as Teach for America (TFA) maintain that individuals who are well prepared in content knowledge can move into the classroom with minimal training and be effective teachers (Costigan, 2005). Ball (1990) posits that without a deep understanding of subject matter content, teachers would be unable to generate accurate explanations or representations on the fly in response to student questions. Subject matter knowledge is critical to good teaching; teachers must be able to identify learner misconceptions and without a strong knowledge base, identifying and addressing learner misconceptions would not be possible (Magnusson, et al. 1999; van Driel, Verloop, & de Vos, 1998; Veal & MaKinster, 1999). However, Zeidler (2002) suggests that subject matter knowledge alone is insufficient for good teaching and that experience in the classroom greatly influences teachers' ability to transform their subject matter knowledge into a form of knowledge more likely to be understood by learners. Cochran, King, and DeRuiter (1991) noted clear distinctions between a science teacher and a science content specialist or scientist:

Teachers are different from biologists, historians, writers or educational researchers, not necessarily in the quality or quantity of their subject matter knowledge, but in how that knowledge is organized and used. For example, experienced science teachers' knowledge of science is structured from a teaching perspective and is used as a basis for helping students to understand scientific concepts. A scientist's knowledge, on the other hand, is structured from the research perspective and is used as a basis for the construction of new knowledge in the field (p. 5).

Darling-Hammond (2000) described an effective teacher as one who learns from teaching rather than one who has finished learning how to teach. Bond, Smith, Baker, and Hattie (2000) asserted that experienced teachers hold extensive knowledge of teaching, learners, and learning including deep knowledge of subject matter and effective representations; a greater repertoire of instructional strategies; and strong ability to read cues from learners. Berliner (2001) noted that the time required for the development of expertise differs within each field but estimated that a reasonable time for expertise to develop in teaching appears to be 5 years or more. Therefore, all of the teacher participants in this study have taught for a minimum of five years with an overall average teaching experience of 13 years.

Models of Teacher Knowledge

Shulman (1986) introduced a model of teacher knowledge which identified a specialized form of knowledge unique to teachers and teaching, distinguishing teachers from subject matter specialists. Shulman's (1986) model identified three general domains of teacher knowledge as content knowledge, pedagogical content knowledge (PCK), and curricular knowledge. Content knowledge includes knowledge of substantive structures, the organization of basic principles, laws, and concepts within the discipline, and knowledge of syntactic structures, the process through which new knowledge is generated and validated (Schwab, 1978; Shulman, 1986). Pedagogical content knowledge

(PCK), the second domain of teacher knowledge in Shulman's (1986) model, exists at the intersection of content knowledge and pedagogy. Shulman (1986) noted that as PCK develops, teachers transform their subject matter knowledge to enhance students' understanding through the most powerful analogies, accurate representations, and effective instructional strategies. Shulman (1986) posited, "If teachers were to be successful they would have to confront both issues (of content and pedagogy) simultaneously, by embodying "the aspects of content most germane to its teachability" (Shulman, 1986, p. 9). Curricular knowledge, the third aspect of teacher knowledge, includes knowledge of programs, resources, and instructional materials designed for teaching specific topics (Shulman, 1986). Curricular knowledge supports the formulation of connections between topics to build upon students' prior knowledge and provide necessary scaffolding for future learning.

Shulman (1987) posited that "PCK blends content and pedagogy into an understanding of how particular topics, problems, or issues are organized for instruction, represented, and adapted to a diverse student audience" (p. 8). Knowledge of subject matter was perceived by Shulman (1986) as critical to teaching because teachers must have a deep understanding of content including both substantive and syntactic structures to formulate accurate explanations and identify students' misconceptions. But Shulman (1986) noted that knowledge of teaching included more than subject matter knowledge. He laid the foundation for the concept of a professional knowledge base for teaching by identifying multiple components beyond subject matter knowledge. Shulman (1987) posited that the development of teacher knowledge involves a dramatic shift in teacher thinking from a professional understanding of science content to an awareness of new

ways in which to organize, represent, and engage students in learning science. This professional knowledge of teaching informed the transformation of content knowledge into a form of knowledge that could be understood by students.

Grossman’s (1990) model of teacher knowledge (see Figure 1) expands upon Shulman’s ideas and includes additional detail. Grossman’s (1990) model emphasizes four general areas of teacher knowledge: (1) knowledge of subject matter (including syntactic and substantive structures), (2) general pedagogical knowledge, (3) knowledge of context, with the centerpiece identified as (4) pedagogical content knowledge (PCK). Grossman’s (1990) model of teacher knowledge is shown below in Figure 1.

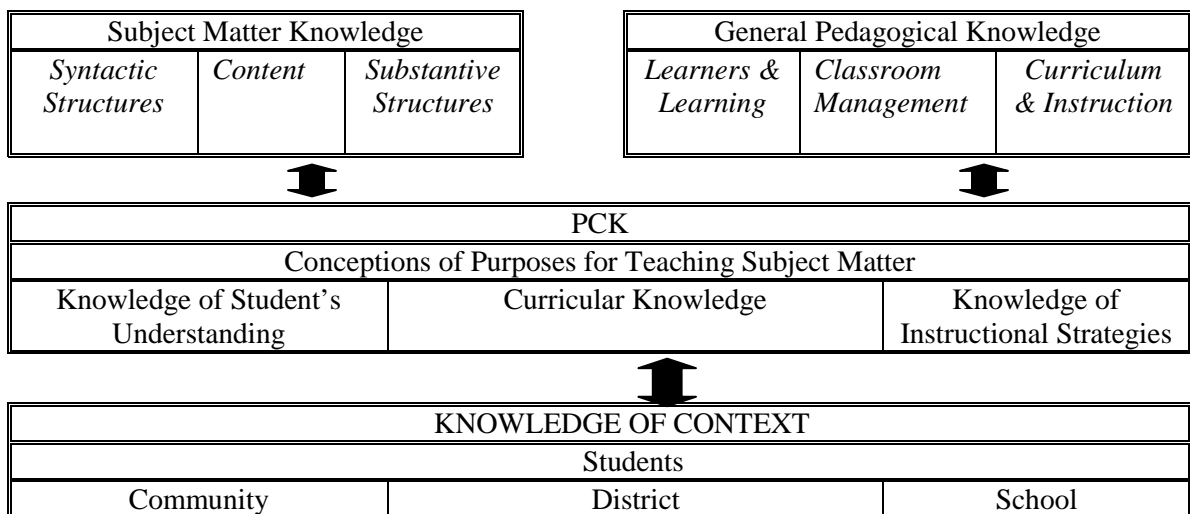


Figure 1: *Grossman (1990) model for pedagogical content knowledge*¹

A description of the knowledge domains within the Grossman (1990) model follows:

- *General pedagogical knowledge:* This general form of teacher knowledge references the knowledge related to the organization of the classroom, curriculum, students, and materials. Classroom management is a key focus of this form of knowledge.

¹Note: From *The making of a teacher: Teacher knowledge and teacher education* by P.L.Grossman, 1990, p. 5. New York: The Teachers College Press.

- *Subject matter knowledge*: Subject matter knowledge for science teaching includes knowledge of content and knowledge of both syntactic and substantive structures. This form of knowledge has the potential to strongly influence how teachers represent content to students and design learning experiences and strategies to support students' learning.
- *PCK*: Grossman (1990) identifies three components of knowledge as PCK including conceptions of purposes for teaching subject matter, knowledge of students, instructional strategies, and curriculum, thus, expanding Shulman's (1986) concept of PCK.
- *Knowledge of context*: Grossman (1990) identifies knowledge of educational context as the knowledge of the community, district, school, students, expectations, and constraints. Teachers draw upon their contextual knowledge to adapt general content to their students and to the demands of the school.

The Grossman (1990) model incorporates conceptions of purposes for teaching subject matter, knowledge of students as learners, knowledge of curriculum, and knowledge of instructional strategies as PCK and identifies knowledge of context, content, and general pedagogical knowledge as components of the model which contribute to and influence teachers' PCK. It is important to note that the arrows between the domains of teacher knowledge in the Grossman (1990) model indicate the reciprocal nature of the model in that these knowledge domains influence one another and create a complex and interactive form of knowledge unique to teaching. Sources of teacher knowledge identified by the Grossman (1990) model include (a) observation of experienced teachers, (b) education within the context of a specific discipline (e.g., biology, chemistry, etc.), (c) methods courses during teacher education, and (d) classroom teaching experience.

The models of teacher knowledge proposed by Magnusson, Krajcik, and Borko (1999) expanded upon the earlier models of teacher knowledge proposed by Shulman (1987) and Grossman (1990). The first model of teacher knowledge proposed by

Magnusson et al. (1999) identifies the relationships among the domains of teacher knowledge which include: (1) subject matter knowledge (both substantive and syntactic structures), (2) general pedagogical knowledge, and (3) knowledge of context, and the centerpiece of teacher knowledge (4) pedagogical content knowledge (PCK). Magnusson et al. (1999) argue that subject matter knowledge, pedagogical knowledge, and knowledge of context strongly influence the pedagogical content knowledge held by the teacher. Thus, the model indicates the important influence of subject matter knowledge, pedagogical knowledge, and knowledge of context in shaping teacher PCK. The Magnusson et al. (1999) model of PCK is shown in Figure 2.

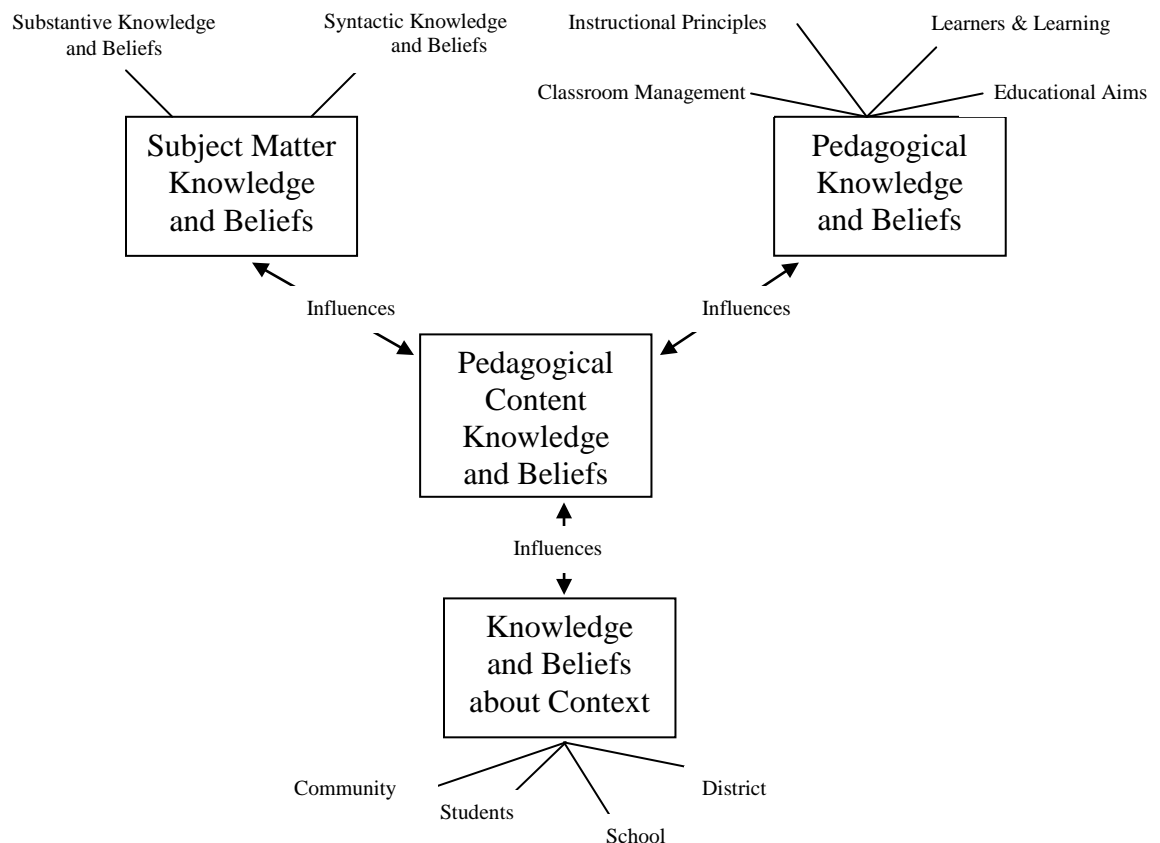


Figure 2: Magnusson et al. (1999) model of teacher knowledge

²Note: From Nature, sources, and development of pedagogical content knowledge for science teaching (p.99), by S. Magnusson, J. Krajcik, & H. Borko, 1999. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining Pedagogical Content Knowledge*. Boston, MA: Kluwer.

The model of teacher knowledge shown in Figure 2 indicates PCK is influenced by the knowledge and beliefs about subject matter, general pedagogy, and context. Next, Magnusson et al. (1999) elaborate on the central components and further delineate categories within PCK as shown in Figure 3.

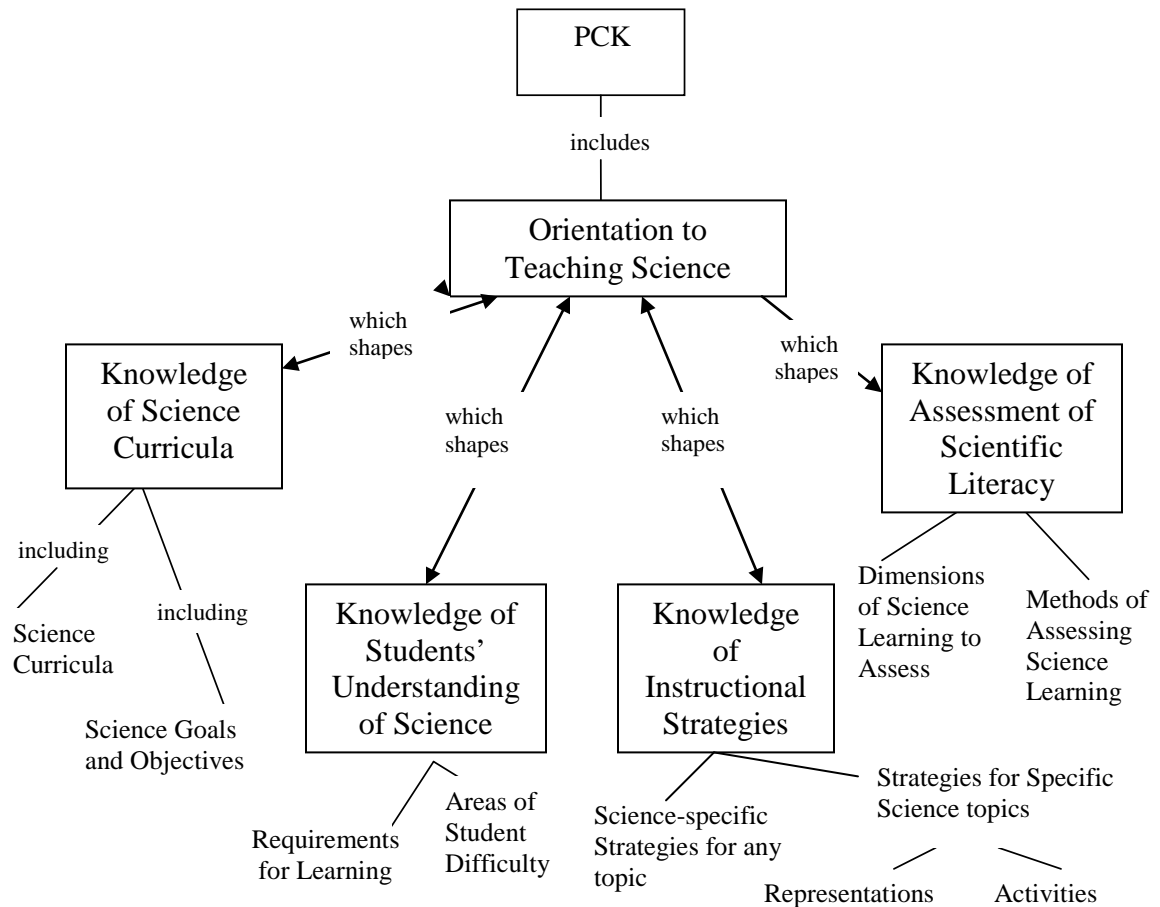


Figure 3: Magnusson et al. (1999) model of PCK

The Magnusson et al. (1999) model of PCK (see Figure 3) is similar to the Grossman (1990) model with two modifications: (1) conception of purposes has been changed to orientation toward science teaching; and (2) knowledge of assessment has been added as a component of PCK. Thus, Magnusson et al. (1999) incorporate “five

³Note: From “Nature, sources, and development of PCK for science teaching.” By S. Magnusson, J. Krajacik, & H. Borko, 1999, p.99. In J. Gess-Newsome & N.G. Lederman (Eds.). *Examining PCK: The construct and its implications for science education*. Boston, MA: Kluwer Academic Press.

components into their PCK model including: (a) orientations toward science teaching, (b) knowledge and beliefs about science curriculum, (c) knowledge and beliefs about assessment in science, (d) knowledge and beliefs about students' understanding of specific science topics, and (e) knowledge and beliefs about instructional strategies for teaching science" (p. 97).

Magnusson et al. (1999) posited the orientation to teaching science is central to PCK as the lens through which all components of PCK are understood, interpreted, and integrated resulting in a unique form of knowledge held by teachers. The model depicts PCK as the result of "transformation of knowledge of content, pedagogy, and context" and indicates the resulting knowledge can spur development of the other components of PCK in turn (Magnusson et al. 1999, p.96). An explanation of the PCK components included in the Magnusson et al. (1999) model of teacher knowledge follows:

- *Orientation to teaching:* Magnusson et al. (1999) describe orientation to teaching science as "the knowledge and beliefs possessed by teachers about the purposes and goals for teaching science at a particular grade level" (p. 97). The orientation that the teacher has for teaching science is a way of conceptualizing science teaching and learning. Teacher orientation acts as a "conceptual map" guiding decisions about learning objectives, implementation of curricular materials, and evaluation of students' learning (Magnusson et al. 1999, p. 97)
- *Knowledge of science curricula:* Curricular knowledge references teacher understanding of the goals and objectives for student learning and the scope and sequence of the scientific concepts to be taught. Teacher knowledge of curriculum consists of two categories: (a) the mandated goals and objectives and (b) specific curricular programs, resources, and materials (Magnusson et al. 1999).
- *Knowledge of students' understanding of science:* This component of PCK includes teacher knowledge of the requirements for student learning of specific scientific concepts and potential learning difficulties student may encounter when learning the concept(s).
- *Knowledge of instructional strategies:* General teaching strategies such as the learning cycle, which have broad application in teaching within a scientific discipline (e.g., biology, chemistry, physics, etc.) are included in this component of PCK, as

well as topic-specific strategies including ways to represent concepts (models, diagrams, pictures, tables, and/or graphs) and engage students with instructional strategies (investigations, experiments, demonstrations, simulations, problems or examples) to facilitate student learning of specific concepts in science (Magnusson et al. 1999).

- *Knowledge of assessment:* This component of PCK consists of (a) knowledge of the dimensions of science learning important to assess and (b) knowledge of assessment strategies and methods through which students' learning can be assessed (Magnusson et al. 1999). Methods of effective assessment include informal, formative, and summative evaluations implemented to reveal student understanding implemented to assess students' understanding of scientific concepts.

The Magnusson et al. (1999) model of PCK underscores the centrality of teachers' orientations to science teaching. The orientation to science teaching is identified as the lens through which the other components (knowledge of students as learners, representations and instructional strategies, assessment, and curriculum) are interpreted and integrated to guide instructional decisions during teaching and planning. All five components of the Magnusson et al. (1999) model are influenced by teacher subject matter knowledge and the context in which teaching is taking place.

The Magnusson et al. (1999) model of PCK for science teaching provided the conceptual framework for my study. For my research, I identified PCK as the transformation of subject matter knowledge, pedagogical knowledge, and contextual knowledge into a form of knowledge unique for teaching a specific topic. My description of PCK is in alignment with Shulman's (1986) definition of PCK and the PCK models proposed by Grossman (1990) and Magnusson et al (1999).

This study investigated the PCK held by experienced biology teachers for teaching a specific topic, osmosis and diffusion, to 10th grade high school biology students. I modified the Magnusson et al. (1999) description of orientations for science teaching based upon the mathematics education literature (Ernst, 1989; Handal, 2003)

and the science education literature (Koballa, Glynn, Upson, & Coleman, 2005). Science and mathematics education literature identifies sub-categories within teacher orientations to address perceptions of the teacher and student roles in teaching and learning, as well as ideal images of teaching (Ernst, 1989; Handal, 2003; Koballa et al., 2005). I describe orientation for science teaching to include five sub-categories: (1) goals and purposes for teaching; (2) perception of teacher role; (3) perception of student role; (4) ideal images of teaching; and (5) perception of science as a discipline. The expansion of the dimensions of the orientation to teaching science is based upon the work of Brown, Abell, and Friedrichsen (2008). By expanding the definition of teacher orientation to science teaching and focusing on the topic-specific nature of PCK held by experienced teachers, I believe that I can better understand the role of orientations to science teaching and the other components of PCK within the context of experienced teachers' PCK for teaching osmosis and diffusion.

Orientations to Science Teaching

The orientation toward science teaching represents the way in which the teacher conceptualizes science teaching (Magnusson et al. 1999). Hence, the orientation to science teaching serves as a conceptual map that guides instructional decisions during planning and teaching (Borko & Putnam, 1996).

Constructivist orientation to science teaching. Constructivist perceptions of teaching and learning have had a strong influence on science education during recent years (Mayer, 2000). Driver, Asoko, Leach, Mortimer, and Scott (1994) describe the constructivist perception of teaching as engaging students as active participants in learning and supporting students as they make sense of new ideas by reflecting upon their

experiences with the phenomenon. The constructivist view of learning recognizes that students bring their knowledge of the world and how the world works into the classroom (Bybee, 1997; Driver et al. 1994). To make sense of new ideas, students use their prior knowledge and experiences as well as the first-hand knowledge gained from explorations of phenomena. Teachers holding a constructivist orientation perceive students as active participants in learning and teachers as facilitators of learning (Fosnot, 1996). Through a constructivist lens, learning opportunities are designed to engage students first in explorations and, second, to construct knowledge from their experiences. Glynn, Yeany, and Britton (1991) describe the constructivist orientation to science teaching and learning as an active interaction between teachers and learners. It is through this interaction that students begin to make sense of their experiences with phenomena. Teachers with a constructivist orientation engage students in explorations of phenomena prior to introducing and explaining the phenomena to students.

Knowledge-transmission orientation to science teaching. Teachers with a knowledge-transmission orientation to science teaching maintain a teacher-centered focus in their instruction. Kember (1998) identified a teacher-centered orientation as focused on transmitting knowledge to students through lecture. Teachers holding a knowledge-transmission orientation to science teaching implement instructional strategies focused on teacher-centered strategies, (e.g., lecture) with the teacher as leader and director of learning (Kember (1998).

Taxonomy of PCK

Veal and MaKinster (1999) proposed a taxonomy of PCK (see Figure 3) to provide a categorization scheme for future studies of PCK development in teacher

education. The General Taxonomy of PCK (Veal & MaKinster, 1999) addresses the hierarchical relationships of three levels of teacher knowledge: (a) discipline-specific PCK (e.g., English, math, history, or science), (b) domain-specific PCK (e.g., physics, chemistry, geology, or biology), and (c) topic-specific PCK (e.g., genetics or evolution).

Veal and MaKinster (1999) argue the General Taxonomy of PCK provides a classification system to more accurately identify and address distinctions among knowledge bases required for teaching content in each of the three levels acknowledged within the model. Thus, the model indicates PCK is unique to different levels of specificity. For instance PCK necessary for teaching science is different from that necessary for teaching mathematics. The nature of PCK for teaching biology is different from that necessary for teaching physics. The Veal and MaKinster (1999) taxonomy of PCK is shown below in Figure 4.

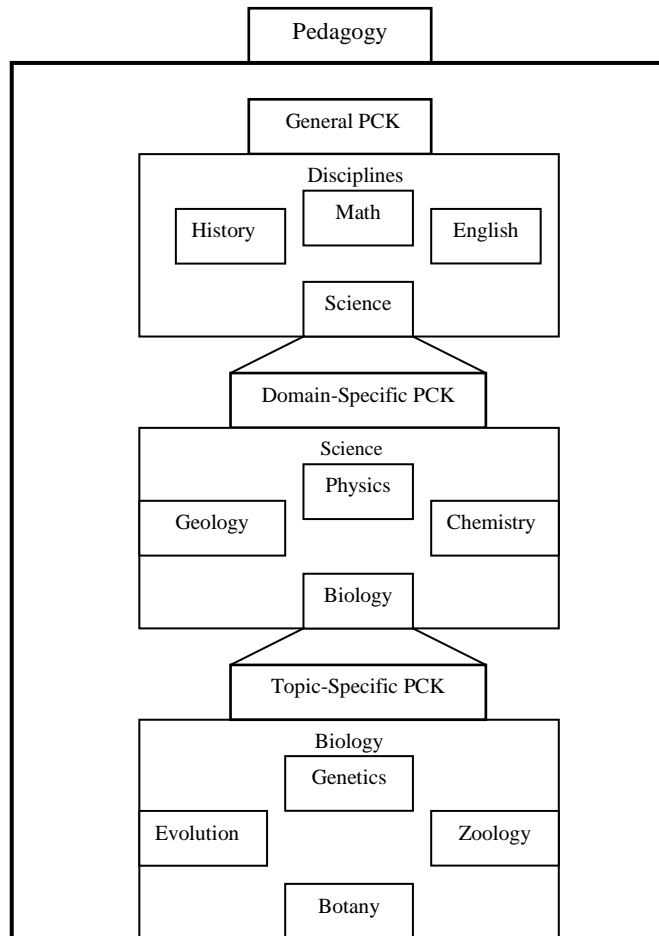


Figure 4: Veal and MaKinster (1999) hierarchical model of teacher knowledge⁴.

Teaching specific topics within a domain of science necessitates PCK which includes knowledge of potential student learning difficulties as well as knowledge of the most effective representations, instructional strategies, curricular resources, and assessments for teaching a specific topic. A discussion of the categories within the General PCK Taxonomy follows:

- *General PCK.* The first level within this taxonomy is General PCK, identified as knowledge necessary for teaching disciplines or subject areas such as science. This level of PCK employs the processes, purposes, and content specific for teaching science. The learning cycle would be an example of general PCK.

⁴Note: From “PCK taxonomies” by W.R.Veal and J.G. MaKinster, 2001, *Electronic Journal of Science Education*, 3 (4) (Retrieved on August 12, 2009, from <http://wolfweb.unr.edu/homepage/crowther/ejse/svec.html>).

- *Domain specific PCK.* The next level of PCK is defined as the knowledge required for teaching a specific domain within science, such as biology or chemistry. Each domain or subject area of science is associated with a unique set of concepts, laws, theories, terms, and topics. Teacher knowledge for biology is unique from that for teaching other domains in science. The distinction between teacher knowledge required to teach within a discipline of science requires knowledge, tools, and purposes specific to that domain of science. For example, teacher knowledge for teaching dissection labs is specific to teaching biology.
- *Topic-specific PCK.* The most specific level of the taxonomy is identified as topic-specific PCK. Teacher knowledge at this level consists of a repertoire of knowledge, skills, methods, and abilities of all three levels of the taxonomy as well as knowledge of specific terms, concepts, and processes within the topic. Topic-specific PCK includes teacher knowledge of content, representations (analogies, models, pictures, etc.) instructional strategies (demonstrations, investigations, experiments, etc.), assessments, and curriculum focused on a specific topic within a domain of science. For example, the teacher knowledge required to teach cell biology includes knowledge of students' misconceptions and learning difficulties specific for cell biology as well as knowledge of examples, diagrams, analogies, demonstrations, and laboratory investigations specific for teaching cell biology and not applicable to other topics in biology.

It is important to note the taxonomy does not suggest that the acquisition of teacher knowledge is linear, but instead delineates between general PCK for teaching science, domain-specific PCK, and knowledge required for teaching specific topics (e.g., photosynthesis, cellular respiration, diffusion, and osmosis) within a scientific domain.

The Veal and MaKinster (1999) model provides additional insight into the nature of PCK due to the emphasis placed upon teacher knowledge for teaching specific topics in biology. The topic-specific PCK necessary for teaching osmosis and diffusion would be very different from that for teaching genetic inheritance. Both topics are likely to be taught in a high school general biology course to the same students; however, each topic would require an understanding of specific potential learner difficulties, preconceptions and misconceptions associated with the topic, specific knowledge of representations,

instructional strategies, assessments, and curricular resources necessary to create meaningful learning opportunities within that specific topic.

5E Instructional Model

The NRC (1999) posits effective learning takes place when students' are active participants in learning, challenged to make and test predictions, and support explanations with evidence. Hence, "ideas are best introduced when students see a need or a reason for their use; this helps them see relevant uses of the knowledge to make sense of what they are learning" (NRC, 1999, p. 127). Historically, science educators have explained learning within the context of three categories: transmission, maturation, and construction (Bybee, 1997). Only the constructivist perspective assumes students to be active participants in learning (Bybee, 1997; Bybee, Taylor, Gardner, Van Scotter, Powell, Westbrook, & Landes, 2006). In contrast, the transmission perspective assumes students to be empty vessels with the teacher as teller, while the maturation perspective assumes students will open to new knowledge as they mature (Bybee, 1997). Dewey (1933) noted an effective instructional sequence followed the scientific process and provided students with an opportunity to formulate and test hypotheses. In the 1960s, the Atkin and Karplus (1962) learning cycle incorporated a student-centered theme of exploration prior to the introduction of the concept.

A contemporary version of the Atkin/Karplus (1962) learning cycle, the 5E instructional model has constructivism as the theoretical foundation and assumes that students bring their own ideas, experiences, and prior knowledge into the classroom and learn as active participants (Bybee, 1997). The 5E instructional model includes five phases: Engage, Explore, Explain, Elaborate, Evaluate (Bybee, 1997; Bybee et al. 2006).

Actively engaged in learning science, students “redefine, replace, and reorganize their initial explanations, attitudes, and skills” (Bybee, 1997, p. 167). The teacher facilitates learning through explorations of phenomena during which students formulate and test predictions, reflect upon observations and experiences with the phenomena to develop explanations and apply new knowledge to novel scenarios (Bybee, 1997; Bybee et al. 2006; DeBoer, 1991; Dewey, 1933; Herbart, 1901). I describe the five phases of the 5E instructional model within the following sections.

Engagement. During the first phase, the teacher engages students through brief activities that focus students’ attention on the phenomenon, stimulate curiosity, and reveal prior knowledge. The teacher makes connections between a new concept and students’ prior knowledge and experience, making the concept relevant to students (Bybee, 1997). Thus, by focusing students’ attention and making relevant connections, the teacher initiates the learning task.

Exploration. Before introducing the concept, the teacher challenges students to conduct an exploration and formulate and test predictions, make observations, record data, and collaborate with peers to develop and test alternative solutions (Bybee, 1997). This phase of the model engages students in a common experience, emphasizing scientific knowledge, processes, and skills.

Explanation. Following the exploration, students review, analyze, and interpret their observations and data. During this phase, the teacher “focuses students’ attention on particular aspects of their engagement and exploration experiences and provides opportunities to demonstrate their conceptual understanding, process skills, or behaviors” (Bybee, 1997, p. 178). Hence, students may realize their prior ideas provide limited

explanations at best and seek new ways to explain their observations. The teacher uses representations (e.g., models, analogies, metaphors, computer animations) to enhance students' conceptual understanding. New scientific vocabulary, unique to the concept, is introduced at this time to expand students' knowledge. The teacher facilitates whole class discussions and encourages students to share their ideas, experiences and observations developing explanations supported with evidence (Bybee, 1997).

Elaboration. During the elaboration phase, students are challenged to apply their knowledge of the concept to novel situations. Through new experiences with the concept, students draw upon knowledge gleaned from the engage, explore, and explain phases to deepen their conceptual understanding, enhance their skills, and broaden their understanding of science (Bybee, 1997).

Evaluation. The evaluation phase of the model encourages students to reflect upon their knowledge and assess their own learning learning. This phase of the model also provides opportunities for teachers to assess student learning and the effectiveness of their instruction (Bybee, 1997). Evaluation of students' conceptual understanding of phenomena through formative assessment has the potential to inform instructional decisions throughout the phases of the instructional model.

Content Representation (CoRe)

Descriptions of teacher knowledge can be found throughout education literature, however, specific examples of teacher knowledge that actually inform instructional decisions during planning and teaching are more difficult to identify. Loughran et al. (2004) and Loughran et al. (2006) suggest that the knowledge of teaching possessed by teachers can only be clarified when teacher thinking can be revealed and understood.

Loughran et al. (2006) have developed a means of documenting concrete examples of teacher knowledge. The Content Representation (CoRe) is used to assess multiple aspects of teacher knowledge including content knowledge, the goals and purposes of the lesson, the instructional strategies and representations to be implemented within the lesson, and the means of assessing student understanding during the lesson (Loughran et al. 2006; Loughran et al. 2004). Thus, a window can be opened into teacher thinking to investigate how the components of teacher knowledge are drawn upon when teachers make instructional decisions during planning and teaching.

Content representations for this study were created by reviewing teacher interviews, videotapes of lessons, and lesson artifacts. The goal was to create an accurate depiction of lesson content as well as the representations, instructional strategies, curricular sequence, and assessments implemented by each participant.

Diffusion and Osmosis

All experienced teacher participants in this study were 10th grade biology teachers and each was observed teaching two consecutive lessons on osmosis and diffusion. By observing teachers teaching the same concept, I gained greater insight into the nature of the topic-specific PCK held by experienced teachers.

Three considerations informed my choice of diffusion and osmosis as the lesson topic for my research. First, diffusion and osmosis are key concepts in biology and form the basis for understanding life processes. The *National Science Education Standards* (NSES) (NRC, 1996) and American Association for the Advancement of Science (AAAS) *Benchmarks for Scientific Literacy* (1993) identify osmosis and diffusion as concepts critical for students' understanding of homeostasis within living systems and the

diffusion of water across a cell membrane. Second, the phenomena require students to integrate their knowledge of: (a) biology, in terms of cell membrane structure and function; (b) chemistry, regarding the particulate nature of matter and relative concentrations of solutes and solvents; and (c) physics, in terms of random molecular motion and collisions as the driving force for both diffusion and osmosis. Because of the integrated nature of diffusion and osmosis, the concepts are challenging for students to comprehend and difficult for teachers to teach. Third, state curricular guidelines mandate the inclusion of diffusion and osmosis through the Course Level Expectations (DESE, 2009); all tenth grade biology teachers include diffusion and osmosis in their tenth grade biology curriculum (DESE, 2009).

The Department of Elementary and Secondary Education (DESE) identifies the following course level expectations for teaching osmosis and diffusion:

- Strand 3: Characteristic and Interactions of Living Organisms;
 - Level 2: Living organisms carry out life processes in order to survive;
 - Concept F: Cellular activities and responses can maintain stability internally while external conditions are changing (homeostasis);
 - Biology I: a: Explain the significance of the selectively permeable membrane to the transport of molecules. b: predict the movement of molecules across a selectively permeable membrane (i.e., diffusion, osmosis, active transport) needed for a cell to maintain homeostasis given concentration gradients and different sizes of molecules (DESE, 2009).

Diffusion and osmosis are topics critical to students' comprehension of important life processes. Examples of passive transport, these processes explain homeostasis, water intake by plants, transport of water and nutrients in living systems, and turgor pressure in plants (Christianson & Fisher, 1999; Friedrichsen, & Pallant, 2007; Johnstone & Mahmond, 1980; Odom & Barrow, 1995; Zuckerman, 1993). Diffusion is referenced in high school biology textbooks as the tendency for molecules of any substance to spread

out into surrounding available space, driven by random molecular motion, and moving from higher to lower concentrations (Campbell & Reese, 2002; Christianson & Fisher, 1999; Johnstone & Mahmond, 1980; Miller & Levine, 2002; Odom & Barrow, 1995). Osmosis is specifically defined as the diffusion of water from higher to lower concentrations across a semipermeable membrane (Campbell & Reese, 2002; Christianson & Fisher, 1999; Johnstone & Mahmond, 1980; Miller & Levine, 2002; Odom & Barrow, 1995). Both processes are driven by molecular kinetic energy or energy of motion and as a result of this continuous and random molecular motion, molecules tend to move from areas of higher concentration into areas of lower concentration (Campbell & Reese, 2002; Miller & Levine, 2002; Odom & Barrow, 1995; Tekkaya, 2003; Zuckerman, 1993).

Key vocabulary terms associated with osmosis and diffusion include: (1) hypertonic - when comparing two solutions, the solution with the greatest concentration of dissolved solid and the least concentration of solvent, (2) hypotonic - when comparing two solutions, the solution with the least concentration of dissolved solid and the greatest concentration of solvent, (3) isotonic - when the concentration of dissolved solid and solvent in two solutions is equal, (4) concentration gradient - the difference in the concentration of dissolved solid within two solutions separated by a semipermeable or selectively permeable membrane, and (5) semipermeable membrane - a membrane which will only allow certain substances the passage of certain substances (typically determined by molecular size).

Significance of the Study

Data collected from the 2003 TIMSS indicated that eighth graders in five Asian and European countries outperformed eighth graders in the U.S. in science and mathematics (TIMSS, 2003). U.S. eighth graders failed to improve their performance on the 2007 TIMSS and fell below their peers in nine Asian and European countries (TIMSS, 2007).

Students in the U.S. are also falling far below their international peers in terms of earning college degrees in science, technology, engineering, and mathematics (STEM) fields; the highest performing countries also grant the largest proportion of college STEM degrees (TIMSS, 2003, 2007). According to a recent report by the United States General Accounting Office (GAO), enrollment in postsecondary education has increased over the past decade; however, the percentage of U.S. students earning degrees in STEM fields has declined (GAO, 2006). These trends are alarming since the workforce of the future must have greater knowledge of science and mathematics along with problem-solving and critical thinking skills to compete in an increasingly technologically sophisticated global environment (Phillips, 2007).

The ability to resolve this issue is further complicated by a projected teacher shortage (Ingersol, 2001, 2006). The National Commission on Teaching and America's Future predicts that approximately 1.7 million teachers in the U.S. are approaching retirement age and likely to retire and leave the profession during the next decade (National Commission on Teaching and America's Future, 2002). When coupled with beginning teacher attrition rates, rising steadily over the past decade, and the projected increase in student enrollment, there is genuine concern about placing qualified and

certified teachers in American classrooms (Ingersol, 2006). The No Child Left Behind (NCLB) Act of 2001 must be considered when new teachers are hired. NCLB mandates that highly qualified teachers be placed in each classroom; attributes for highly qualified teachers include: a baccalaureate degree and state certification in the subject area to be taught and, for middle and secondary teachers, there must be evidence of knowledge of content to be taught via a state test, an academic major, or National Board Certification.

In response to the projected teacher shortage, colleges and universities have developed alternate certification programs (ACP) to provide an alternate pathway to teacher certification for post-baccalaureate candidates (Cochran-Smith, & Fries, 2006; Wilson, Floden, & Ferrini-Mundy, 2001). Mentor teachers play a key role in teacher preparation through ACPs as they provide guidance for prospective teachers during internships. Ninety-six percent of ACPs report that prospective teachers in their programs receive support from mentor teachers (Feistritzer, 2005). The goal is to provide prospective teachers with critical guidance from an experienced mentor during the transition from student to teacher.

Understanding the practice of experienced teachers serving as mentors for prospective teachers has the potential to provide important insights for teacher educators. The nature of teacher knowledge held by experienced biology teachers and how that knowledge guides their teaching can inform science teacher preparation (Aikenhead, 1984). ACP and traditional teacher preparation programs will benefit from insights into the knowledge and practice of experienced teachers because this knowledge can be used to inform instruction within science teacher preparation programs and provide clearer target for the knowledge and practices of prospective teachers. Westerman (1991) reports

that pre-service teachers can benefit from a focus on the practice of experienced teachers and the knowledge that guides their instructional actions and decisions. Such a focus will support a greater awareness of the components of teacher knowledge and the integration of these components during planning and instruction (Aikenhead, 1984; Westerman, 1991). The results from this study contribute to what is known about the PCK of experienced secondary teachers for teaching a specific topic in a general high school biology course.

Organization of the Dissertation

This study is divided into six chapters. Chapter One provides an overview of the study including the rationale, research questions, conceptual framework, and study significance. The conceptual framework for the study includes Pedagogical Content Knowledge, the taxonomy of PCK, osmosis and diffusion, and content representation. In Chapter Two, I review the mathematics and science education literature for both prospective teachers and experienced teachers.

Chapter Three outlines the qualitative approaches used in this study. This includes a description of the research tradition, research methodology, and the design of the study. I included details of the context of the study including a brief explanation of the design of the ACP and demographic data for high schools of the study participants. I also describe data collection strategies and data analysis methods. The chapter concludes with a description of the trustworthiness of the design and implementation of the study.

Chapter Four and Five describe the findings of the study. In Chapter Four I provide six case profiles, one for each of the participants. The purpose of Chapter Four is to provide evidence for the assertions made in Chapter Five.

In Chapter Five I provide a cross-case analysis and assertions that emerged from the data. Throughout this chapter I reference the profiles presented in Chapter Four. Additionally, I synthesized data from Chapter Four into tables that are representative of the knowledge of PCK components held by the research participants.

Chapter Six is the final chapter. This chapter includes a summary of the findings in relation to the research questions and a discussion of the findings relative to the research literature. The chapter concludes with implications for practice and recommendations for future research.

CHAPTER TWO: REVIEW OF LITERATURE

In Chapter Two, I review the literature related to my study. The areas of research addressed include (1) the nature teacher of knowledge held by prospective mathematics and science teachers, (2) the nature of content knowledge for teaching mathematics held by experienced mathematics teachers, (3) the nature of pedagogical content knowledge held by experienced science teachers, (4) topic-specific PCK for teaching osmosis and diffusion, and (5) how this study addresses the gaps in the literature. This chapter addresses the nature of teacher knowledge held by both prospective and experienced teachers of mathematics and science. I included mathematics education research examining both prospective and experienced teachers of mathematics to add an important perspective. Research examining teacher knowledge for teaching mathematics provides a new perspective for understanding the nature of teacher knowledge for teaching concepts in science. Mathematics education literature addresses the packaging of teacher knowledge into discrete units which include conceptual understanding of mathematics as well as knowledge of learners and instructional strategies for making concepts in mathematics understandable for students. Hence, a review of prospective teacher learner and the knowledge held by experienced teachers provides another perspective on the knowledge for teaching mathematics as well as insight into the integration of knowledge of content, students, instructional strategies, and assessments for effective mathematics teaching.

Science education research investigating pedagogical content knowledge for teaching science largely addresses the development of teacher knowledge in prospective teachers rather than the knowledge held by experienced science teachers. To understand

the nature of knowledge for teaching mathematics and science among experienced teachers, it is important to first consider the manner in which the knowledge for teaching mathematics and science develops among prospective teachers. The goal for this review of education literature is to address the following questions: (a) How does pedagogical content knowledge develop among prospective teachers of mathematics and science? (b) What is known about the knowledge for teaching held by experienced mathematics teachers? (c) What is known, in general, about the components of pedagogical content knowledge (PCK) held by experienced science teachers? and (d) What is known about experienced science teachers' PCK for teaching diffusion and osmosis?

The Nature of PCK

The concept of pedagogical content knowledge (PCK), first proposed by Shulman (1987), identifies a form of knowledge unique to teachers, teaching and students' learning. Hassard (2005) described PCK as the knowledge possessed by teachers which allows them to teach effectively within a discipline as opposed to the knowledge of the discipline itself. Berliner (2001) noted education research has demonstrated qualitative differences between the nature of knowledge held by novice teachers and that held by experienced teachers. To understand the nature of pedagogical content knowledge (PCK) held by experienced mathematics and science teachers it is necessary to note how this knowledge develops among prospective teachers. Hence, the following sections address the development of PCK among prospective teachers of mathematics and science.

Teacher Knowledge Held by Prospective Teachers of Mathematics and Science
Prospective Mathematics Teachers

Borko and Livingston (1989) investigated prospective mathematics teachers and their mentor teachers during a field experience and found the experienced mentor teachers have developed more extensive, better-integrated stores of subject-matter knowledge, knowledge for teaching mathematics, and teaching experience upon which to draw during planning and reflection. As a result, the experienced teachers demonstrated greater flexibility in their teaching, were able to respond quickly and effectively to students' learning difficulties, and were able to present concepts to students in different ways. This degree of interconnected subject-matter knowledge and knowledge for teaching mathematics was non-existent among prospective teachers who demonstrated minimal flexibility in their teaching and were not able to predict nor respond effectively to students' learning difficulties (Borko & Livingston, 1989).

Archer (2000) compared beliefs about the nature of mathematics and its place in the curriculum between ten prospective secondary mathematics teachers and seventeen prospective primary teachers. The views of the secondary teachers were consistent with the curricular organization of mathematics at the secondary level and reflective of the organization experienced by the prospective teachers as students in high school mathematics. The primary teachers had a more holistic view of mathematics similar to their experiences as elementary mathematics students (Archer, 2000). Hence, prospective teachers explained their conceptions of mathematics were largely shaped by their experiences as students; the researchers noted both groups of prospective teachers were

inclined to teach mathematics in the manner in which they were taught as students (Archer, 2000).

Nathan and Petrosino (2003) examined the relationship between the subject matter expertise of forty-eight prospective secondary mathematics teachers and their ability to predict students' learning difficulties associated with solving algebra problems. The researchers posit subject matter expertise alone is insufficient for predicting students' difficulties as learners and to understand how students learn content (Nathan & Petrosino, 2003). Hence, the prospective teacher participants are well versed in mathematics content but not sure of how to most effectively represent content for students to facilitate student learning.

Ball (2001), Ball, Bass and Hill (2004), and Leinhardt and Smith (1985) conceptualize content knowledge for teaching mathematics as common and specialized knowledge. The researchers describe common knowledge as the essential algorithmic and procedural knowledge for problem solving, whereas, specialized knowledge was defined as including the knowledge of skills, representations, and strategies for teaching mathematics (Ball, 2001; Ball et al. 2004; Leinhardt & Smith, 1985). Hence, common mathematical knowledge, while necessary for effective teaching, is insufficient without the specialized knowledge of how to make concepts in mathematics understandable for students (Ball, 2001; Ball et al. 2004; Leinhardt & Smith, 1985).

The importance of teacher understanding of students as learners of mathematics is underscored by the findings of Putnam and Borko (2000), Brown, McNamara, Hanley, and Jones, (1999) and Cady, Meier, Meier, & Lubinski, (2006). These studies suggest that an understanding of students as learners and a strong emphasis on potential learning

difficulties enhances the development of content knowledge for teaching mathematics among prospective and novice teachers of mathematics. The emphasis on learner difficulty stimulates consideration of other components of teacher knowledge including instructional strategies, as well as representations, examples, and manipulatives that clarify concepts for learners. Cady et al. (2006) posit that prospective mathematics teachers must construct their own knowledge about teaching, learning, and learners. Hence, reflection upon teaching in conjunction with a focus on students as learners, and potential learning difficulties informs prospective teachers' instructional decisions during planning and teaching. The development of an internal locus of authority is perceived by Brown et al. (1999) as an indicator of prospective teachers' ability to develop teacher knowledge necessary for successful teaching of mathematics. Prospective mathematics teachers who maintain the view that their instructors, mentor teacher and others in authority possess all of the answers are far more likely to rely upon and accept guidance of others rather than constructing their own knowledge of teaching (Brown et al. 1999). Whereas, prospective teachers maintaining an internal locus of authority are more likely to construct knowledge for teaching mathematics through their classroom experience and teaching practice.

Prospective Science Teachers

Sarason (1990) and Adams and Krockover (1997) noted prospective teachers construct knowledge for teaching from their experiences as learners and their prior conceptions about science teaching. Sarason (1990) posits the development of PCK among prospective teachers is largely influenced by individual and contextual factors and prospective teachers tend to teach in the manner in which they were taught. Lederman,

Gess-Newsome, and Latz (1994) found that as prospective teachers move through teacher preparation programs, their knowledge becomes interconnected. Investigating reflective practice among prospective teachers Loughran (2002) found professional knowledge developed through an effective reflective practice offers important insights into teaching practice focused on the views of the teacher and the student. Developing an understanding of how teacher actions affect students' thinking and learning enhances prospective teachers' perception of the learning environment. Hence, a reflective practice encourages prospective teachers to consider their actions as teachers from the perspective of students' thinking and learning (Loughran, 2002).

Friedrichsen, Abell, Paraja, Brown, Lankford, and Volkmann (2009) investigated the influence of prior teaching experience upon prospective and novice biology teachers' knowledge for teaching upon entry into an alternative certification program. Both prospective and novice teachers demonstrated an information-transition approach to science teaching as evidenced by the sequence of instruction which followed an inform-verify-practice sequence and perceived learning as memorizing information (Friedrichsen et al. 2002). Study findings suggest effective teacher preparation programs must include effective mentoring with a strong emphasis upon reflection as well as collaboration among interns "to assess student work, reflect on practice, challenge common myths of teaching, and share best practices" to support the development of discipline and topic-specific PCK (p. 376).

A study by Davis (2003) investigated the development of PCK among prospective teachers through the lens of knowledge integration. Davis (2003) defined knowledge integration as the process of adding new ideas and understandings of scientific concepts

while making connections between the concepts and appropriate real-world experiences. Hence, prospective teachers develop PCK as they blend their content knowledge of scientific concepts with their developing knowledge of appropriate representations and instructional strategies to make science content more understandable for students. Davis (2003) posits the knowledge integration perspective analyzes the development of teacher knowledge from the perspective of the teachers' ability to integrate content knowledge with pedagogical knowledge.

Studies conducted by Van Driel, De Jong, and Verloop, (2002) and De Jong and Van Driel (2005) investigated the development of PCK among prospective teachers within the context of a post-graduate alternative teacher certification program in the Netherlands. Concerns about switching from macroperspectives to microperspectives during chemistry lessons were rarely identified by the prospective teachers as potential learning difficulties for students. However, after teaching the concepts, all prospective teachers noted students experienced difficulty following teachers' mental jumps from macroscopic to microscopic perspectives (De Jong & Van Driel, 2005). In interviews, prospective teachers reflected on learning difficulties experienced by the students. The authors suggested the development of prospective teachers' PCK was associated with an understanding of students as learners. As prospective teachers' understanding of students as learners developed, the teachers began to consider other ways in which the topic could be represented and taught to address students' difficulties and enhance understanding (De Jong & Van Driel, 2005; Van Driel et al., 2002). As a result of prospective teachers' emerging awareness of the potential for learner difficulties associated with specific content, study findings suggest that a relationship exists between the development of

teachers' PCK with respect to knowledge of difficulties in student learning; indicating a possible starting point for the development of PCK in prospective teachers (De Jong & Van Driel, 2005; Van Driel et al., 2002).

Zemal-Saul, Blumenfeld, and Krajcik (2000) examined changes in the science content representations of two prospective elementary teachers and suggested that there are two components of teacher knowledge involved with knowledge of representations: the knowledge of instructional strategies and the knowledge of learners. The study was organized around two cycles of teaching during which prospective teachers included several representations of concepts within their lesson plans. Each cycle was followed by in-depth reflection through which prospective teachers analyzed their lessons, their teaching, and learner response. Reflection was found to be critical for improvement in planning and teaching; through reflection prospective teachers were able to examine their teaching, representations of content, and response of learners (Zemal-Saul et al. 2000).

Lee, Brown, Luft, and Roehrig (2007) investigated the development of PCK among novice secondary science teachers and found the development of PCK to be driven by teaching experience coupled with reflection. Researchers noted that novice teacher participants held low levels of PCK even though each had a relatively strong background in science suggesting that PCK did not result from knowledge of subject matter alone, but rather from teaching experience coupled with teacher knowledge of subject matter and learners. Carlson (1993) investigated four prospective secondary biology teachers and found when the teachers taught topics for which their knowledge was greater, the teachers asked more demanding questions and engaged students in discussions, providing more opportunities for students to share their ideas. Hence,

Carlson (1993) noted prospective teachers with stronger content knowledge were likely to implement more sophisticated teaching practices. Luft, Roehrig, and Patterson (2003) investigated the development of PCK among novice biology teachers with a focus on two categories: knowledge of student learning and knowledge of instructional strategies. Study participants were in their first year of science teaching and supported with different induction programs. Findings indicated the teachers in the science-focused induction program held more constructivist beliefs and, as a result, enacted more inquiry-oriented lessons than their peers. The researchers emphasize the importance of science-focused induction programs for beginning teachers and suggest teacher knowledge develops through experience in the classroom in which the teacher is responsible for making instructional decisions based upon students' learning as well as state, district, and school guidelines (Luft et al. 2003). Luft et al. (2003) posit subject matter knowledge alone is insufficient for the development of PCK, knowledge of student learning and instructional strategies are critical for tailoring lesson materials and activities to the needs of students and monitoring students' learning (Luft et al. 2003). Changing the beliefs about science teaching and learning were found to be an important consideration in a study investigating a prospective biology teacher conducted by (Crawford, 1999). Findings revealed the secondary teacher was able to change her beliefs about science learning and transform her teaching approach to include additional student-centered strategies. Hence, the teacher's lessons progressed from an information-transmission approach to science teaching to a more student-centered approach focused on inquiry-oriented strategies with the teacher role as facilitator (Crawford, 1999).

Prospective and novice teachers often cite adherence to curricular guidelines and addressing course content as an explanation for implementing an information-transmission approach to science teaching. A study of four prospective secondary teachers by Haney and McArthur (2002) found teachers' concern about adhering to the district science curriculum influenced instructional decisions. As a result, the prospective teachers relied upon traditional lectures to transmit information, placing students in the role of passive learners (Haney & McArthur, 2002). Similar findings were reported by Tabachnick and Zeichner (1999) resulting from a study of 22 prospective elementary and secondary teachers. The researchers found all of the prospective teachers were reluctant to implement student-centered learning activities. Secondary teachers noted concerns about covering curricular content as a constraint for the inclusion of student-centered learning activities, both groups of teachers noted concerns about classroom management (Tabachnick & Zeichner, 1999).

A common theme through the studies discussed within this section is the importance of teaching experience for the development of PCK. The studies stress that content knowledge alone is insufficient for the development of PCK among prospective teachers. Studies by De Jong and Van Driel (2005), Friedrichsen et al. (2009), Lee et al. (2007); Loughran (2002), Luft et al. (2007), Van Driel et al. (2002), Zembal-Saul et al. (2000) noted the importance of reflection on practice, consideration of students as science learners, and collaboration among prospective teachers to identify best practices. PCK is complex and gradually knowledge components are integrated resulting in a form of knowledge which supports teachers in the design of activities, investigations, and materials to enhance and monitor student learning. In the absence of teaching experience

and knowledge of students as learners, instructional decisions are informed by external forces such as state and district guidelines and the science curriculum (Haney & McArthur, 2002; Tabachnick & Zeichner, 1999). Hence, novice teachers perceive an information-transmission approach to science teaching as an efficient means of covering science content rather than a focus on students' learning and understanding of science content.

Knowledge for Teaching held by Experienced Teachers

The following sections address the nature of teacher knowledge held by experienced mathematics and science teachers.

Experienced Mathematics Teachers

Marks (1990) investigated fifth grade mathematics teachers' teaching of equivalence of fractions and identified four components of teacher knowledge: (1) knowledge of students' understanding of fractions, (2) subject matter knowledge for teaching fractions, (3) materials and manipulatives for instruction, and (4) instructional processes. Hence, Marks (1990) elaborated upon Shulman's (1987) initial work to expand the knowledge of subject matter for teaching and emphasize the importance of teachers' knowledge of students' understanding of mathematical concepts, misconceptions held by students about these concepts, and instructional strategies and materials used by teachers to teach these concepts.

An investigation of prospective teachers and their mentors conducted by Borko, Bellamy, and Sanders (1992) examined the knowledge, thinking, and actions of prospective teachers in comparison to their teacher mentors during a field experience. Borko et al. (1992) identified patterns evident in the practice of mentor teachers

including: (a) drawing upon their subject matter knowledge, PCK, and teaching experience to represent lesson content in several ways, (b) making connections between classroom activities and students' lives, (c) understanding of potential student learning difficulties, and (d) monitoring student learning through questioning and observations during lessons. These components of teacher knowledge were not observed in the practice of the prospective teachers. Hence, experienced mentor teachers possessed in-depth understanding of fundamental concepts in mathematics, knowledge of students as learners, and knowledge of instructional strategies. These components of teacher knowledge made it possible for the mentor teachers to present concepts to students in multiple ways, monitor students' learning, and address students' difficulty with content more effectively (Borko et al. 1992).

Ma (1999) compared the knowledge possessed by elementary teachers in mainland China and the United States. She noted the most accomplished teachers in China held a form of PCK described as a profound understanding of fundamental mathematics, while teachers in the U.S. did not hold this depth of knowledge of mathematics. This depth of fundamental knowledge of mathematics possessed by Chinese teachers was noted by Ma (1999) as a critical factor in teachers' understanding of concepts and the difficulties students were likely to have with the concepts. Described as knowledge packages, this form of teacher knowledge includes a sophisticated understanding of the mathematical concepts in terms of important ideas, organization of concepts, as well as the processes and strategies for making these concepts understandable for students (Ma, 1999). Hence, Ma (1999) suggests effective teaching results from the integration of knowledge of mathematics as a domain with the

knowledge of learners' potential learning difficulties, and strategies to support students' conceptual understanding of the concepts to enhance students' learning and achievement in mathematics. Ball and Bass (2000) noted the importance of deep conceptual knowledge for teaching mathematics and found that teachers with deep conceptual understanding of mathematics were able to present content knowledge to their students in different ways. Ball and Bass (2000) described pedagogical content knowledge for mathematics as a special form of knowledge that "bundles mathematical knowledge with knowledge of learners, learning, and pedagogy" (p. 88).

Following a year-long study of teacher work, Ball and Bass (2003) introduced the construct of mathematical content knowledge for teaching. This construct has resulted in a new understanding of the knowledge required for teaching. Similar to PCK, mathematical content knowledge for teaching is defined as knowledge unique to teaching which intertwines content knowledge with an understanding of teaching and learning; hence, knowing mathematics alone is not sufficient, teachers must be able to anticipate and address students' learning difficulties with concepts in mathematics (Ball & Bass, 2003).

The importance of integrating content knowledge for teaching mathematics with knowledge of students as learners was emphasized in a study conducted by Hristovitch and Mitcheltree (2004). The researchers investigated the nature of mathematics teaching and found concepts were often taught as discrete clusters of information failing to build upon students' understanding or make connections between the concepts (Hristovitch & Mitcheltree, 2004). Lacking an understanding of potential learning difficulties, teacher participants experienced difficulty in organizing, sequencing, and identifying conceptual

mathematical prerequisites to engage students with the concepts in a way which supported conceptual understanding (Hristovitch & Mitcheltree, 2004). Findings from the study completed by Hristovitch and Mitcheltree (2004) supported the findings of Ma (1999).

A study conducted by Sherin and Han (2004) investigated mathematics teacher learning through observations, discussions, and reflections upon videotaped lessons. Sherin and Han (2004) posit before student learning improves, teachers learning must occur, and include a blend of mathematics content and pedagogical content knowledge. Sherin and Han (2004) argue teacher learning occurs most effectively when teachers have the opportunity to examine teaching and learning in new ways; hence, video clubs were studied in which members provided videotaped lessons to be observed and discussed by the group. A shift in teachers' thinking occurred as teachers met and discussed videotaped lessons. During earlier meetings, teacher discussions centered on how the lesson was implemented with little attention paid to students' comments and questions during the lesson; however, during the later meetings, teachers analyzed students' questions and answers and compared students' ideas with the learning goals the teacher had hoped to accomplish (Sherin & Han, 2004). Hence, there was greater emphasis placed upon teacher action in relation to students' thinking and comprehension. As teachers participated in critiques of videotaped lessons, they began to focus on different aspects of student-teacher and student-student interactions; as a result, teachers generated new approaches for analyzing student conceptions and teacher actions (Sherin & Han, 2004).

The concept of specialized knowledge for teaching (Shulman, 1987) is clearly addressed in the mathematics education literature. The knowledge for teaching mathematics includes an in-depth understanding of mathematical concepts as well as an understanding of students as learners. Hence, content knowledge for teaching mathematics (Ball, 2001) is representative of Shulman's (1986) description of pedagogical content knowledge. Ma (1999) described the knowledge for teaching mathematics as profound understanding of fundamental mathematics and noted concepts in mathematics were packaged with knowledge of learners, representations, and instructional strategies to make concepts understandable for students. Effective teachers will be able to unpack mathematical concepts, predict learner difficulties, identify effective instructional strategies, and present these concepts to students in ways which are understandable for students (Ball, 2001; Ball & Bass, 2003; Ball et al. 2004; Borko et al. 1992; Hristovitch & Mitcheltree, 2004; Ma, 1999; Marks, 1990; Sherin & Han, 2004).

Experienced Science Teachers

Magnusson et al. (1999) described PCK as “the transformation of several types of knowledge for teaching” (p. 95). The Magnusson et al. (1999) model of PCK identifies five components integrated during planning and teaching including: knowledge of students' understanding of science, knowledge of representations and instructional strategies, knowledge of assessment, and knowledge of curriculum. Shulman (1987) posits the development of PCK results from a change in teacher perspective “from being able to comprehend subject matter for themselves, to becoming able to elucidate subject matter in new ways, reorganize and partition it, clothe it in activities and emotions, in metaphors and exercises, and in examples and demonstrations, so that it can be grasped

by students” (p. 13). Hence, the knowledge for teaching is unique in that it results from a transformation of the knowledge of content and pedagogy possessed by the teacher into a form of knowledge understandable for learners (Shulman, 1986; Magnusson et al. 1999).

Park and Oliver (2008) posit PCK can only be expressed during teaching when teachers transform subject matter to make content more understandable for students. The researchers examined the practice of three experienced teachers petitioning for National Board Certification (NBC) in Adolescent and Young Adult Science. Findings indicate study participants focused on five areas of their teaching practice including: (a) reflection on teaching practices and students’ learning, (b) implementation of inquiry-based instructional strategies, (c) assessment of students learning, (d) understanding of potential student learning difficulties, and (e) implementation of new instructional strategies (Park & Oliver, 2008). As the teacher participants progressed through the certification process, they became more reflective and analytical about their teaching processes, questioned the effect their teaching processes had upon students’ learning, and considered new teaching approaches; in essence, the teachers expanded their existing PCK through the NBC process (Park & Oliver, 2008). The findings of the Park and Oliver (2008) study were in alignment with work by Fernandez-Balboa and Steihl (1995) who posited the development of PCK results from integration of different knowledge components including knowledge of science as well as knowledge of science curriculum, learners, representations, instructional strategies, and assessment. Hence, during the NBC process, teachers expanded and integrated their PCK to develop a more sophisticated form of teacher knowledge.

Baxter and Lederman (1999) posit that pedagogical content knowledge (PCK) consists of an external and internal construct and is “constituted by what a teacher knows, what a teacher does, and the reasons for the teacher action” (p. 158). This finding was supported by studies conducted by Cohen and Yarden (2009) and Hashwey (1985, 2005) which examined the practice of experienced science teachers and concluded PCK resulted from both internal and external factors. Internal factors, described as originating within the teachers themselves, resulted from reflection on their practice as classroom science teachers, and revealed beliefs about teaching, learning, and learners held by the teacher (Cohen & Yarden; 2009; Hashweh, 1985, 2005). External factors result from the educational system within the school and/or district including the district curriculum, professional development opportunities, and the context in which the teachers conduct their practice (Cohen & Yarden, 2009). The researchers posit experienced teachers develop an integrated set of knowledge and beliefs about teaching, learning, and learners which informs their instruction and guides their instructional actions during teaching (Cohen & Yarden, 2009; Hashweh, 1985, 2005). A discussion of the nature of experienced teacher knowledge of the components of PCK as identified by Magnusson et al. (1999) follows.

Orientation to science teaching. Grossman (1990) expanded upon Shulman’s (1987) description of PCK to include teachers’ goals and purposes for teaching, defined as their conceptions of teaching which are “reflected in their goals for teaching particular subject matter” (p. 8). Anderson and Smith (1987) labeled general views about teaching, learning, and learners, as “orientations towards science teaching” (p.99); four orientations were identified to describe different approaches to science teaching including:

(1) science-driven, (2) didactic, (3) discovery, and (4) conceptual change. Nespor (1987) found teacher experiences as a student and as a practitioner resulted in “critical episodes or experiences gained earlier in teaching careers and important to present practices” (p. 320). Thus, two teachers with similar subject matter knowledge of science may teach in very different ways; their beliefs play a greater role in shaping the way in which they teach than their knowledge of subject matter (Nespor, 1987). Hence, teacher beliefs about teaching, learning, and learners inform instructional decisions and influence the teaching approach taken by the teacher. Magnusson et al. (1999) described the orientation for science teaching as “the knowledge and beliefs about the purposes and goals for teaching science at a particular grade level” (p. 97). They researched education literature to identify nine specific orientations for science teaching including: (1) process, (2) academic rigor, (3) didactic, (4) conceptual change, (5) activity-driven, (6) discovery, (7) project-based science, (8) inquiry, and (9) guided inquiry (Magnusson et al 1999, p. 100-101).

A card sorting task, developed by Friedrichsen and Dana (2003), elicited and clarified teacher orientations and beliefs regarding science teaching. Teacher orientations were found to be complex, including both central and peripheral goals. Furthermore, the goals for teaching science shifted with the course, the topic taught, and the grade level of the students (Friedrichsen & Dana, 2003). Friedrichsen (2002) described teacher orientations as influenced by teachers’ beliefs about teaching and learning, students’ attitudes toward science, and readiness for college.

Friedrichsen and Dana (2005) examined the nature and sources of orientations to science teaching among four experienced and highly regarded secondary biology teachers. They

found teachers' orientations to be complex with multiple purposes for teaching biology which included three categories of goals: (1) affective domain goals, (2) general schooling goals, and (3) subject matter goals. Teachers achieved their goals through different means (e.g., stories, field trips, investigations, demonstrations, science competitions) which varied with the beliefs about learners and learning held by the teacher. Differences in course content and student abilities were found to result in variations within the orientation to science teaching; hence, teacher orientation for teaching an advanced or upper level biology course may differ from that held by the same teacher when teaching an introductory biology course. Teacher beliefs and assumptions about teaching, learning, and learners influence how the teachers think about teaching and respond to particular situations (Calderhead, 1996; Friedrichsen & Dana, 2003, 2005). Volkmann and Zgagacz (2004) posited teachers' orientation to science teaching is based upon core beliefs and identity as a teacher and learner.

Lotter, Harwood, and Bonner (2007) investigated teacher conceptions and implementation of inquiry-based instructional strategies of three secondary science teachers. The researchers found that the implementation of inquiry-based instructional strategies may be "constrained by teachers' core conceptions and beliefs about inquiry-based instruction and other reform-based instructional strategies" (p. 1341). Teachers' conceptions of science, students, effective teaching practices, and the purpose of education were noted by the researchers to influence the degree of implementation of inquiry-based instructional practices into their instruction (Lotter et al. 2007).

Studies conducted by Ames and Ames (1984), Meece (1991), and Maehr and Midgley (1996) proposed that schools have a unique and individual culture based upon

shared norms, beliefs, and purposes. Opportunities for teacher learning within schools with an orientation supporting students' mastery included opportunities for teachers to learn, support for instructional innovation, and access to resources; whereas, schools with a performance-orientation focus provided selective access to resources and encouraged competition among teachers (Ames & Ames, 1984; Meece, 1991; and Maehr & Midgley, 1996). Hence, the goals and purposes for instruction emphasized by the school have strong influence on the orientation to science teaching held by the teacher. A study by Deemer (2004) examined relationships among teacher beliefs, instructional practices and classroom goal orientations in high science teaching. Findings indicate school culture, described as an external influence, was an important factor in determining teachers' goals for teaching as well as the nature of their instructional practices (Deemer, 2004).

Samuelowicz and Bain (2001) investigated conceptions of teaching science and identified teacher beliefs as critical factors. Teachers with the goal of facilitating students' understanding of concepts were focused on teacher-centered strategies, however, teachers identifying their purpose as supporting students' development of expertise with content implemented student-centered strategies (Samuelowicz & Bain, 2001). Hence, teacher beliefs about the goals and purposes for teaching and learning exerted a strong influence on their instructional approach. Samuelowicz and Bain (1992) found that teachers may hold both ideal and working conceptions for teaching science. Ideal conceptions are those which the teachers aspired to in their practice, whereas, working conceptions reflected the reality of the context in which the teaching occurred. A study investigating the conception for teaching science among three novice teachers conducted by Koballa, Glynn, Upson, and Coleman (2005) found that the goals and

purposes for teaching science were complex and supported Samuelowicz and Bain's (1992) finding that teachers may hold conflicting goals for teaching science.

Multiple sources for science teachers' orientation to science teaching included prior experiences as a teacher and as a student (Calderhead, 1996; Friedrichsen & Dana, 2005; Nespor, 1987), as well as professional development experiences (Friedrichsen & Dana, 2005). The studies by Friedrichsen and Dana (2003, 2005) investigated the orientations of experienced science teachers and found orientations to be a messy construct. This finding is reflected in the study conducted by Koballa et al. (2005); study findings indicate the goals and purposes for teaching science as complex, consisting of multiple purposes. However, there are few studies in science education literature investigating the nature of experienced teachers' orientation to science teaching in terms of: goals and purposes for teaching science, perception of teacher and students' roles, and ideal images of teaching. Hence, there is a gap in the literature addressing the nature of the orientation to science teaching held by experienced teachers and how their orientation influences their instructional decisions.

Knowledge of representations. Magnusson et al. (1999) define this category of teacher knowledge as referencing specific representations (e.g., models, illustrations, analogies, metaphors, computer animations, diagrams, or examples) to facilitate students' understanding of specific science concepts. Representations are designed to enhance students' understanding of abstract phenomena, test student predictions, or make connections between phenomena and student prior knowledge and experience. Magnusson et al. (1999) posit that effective teachers will judge the effectiveness of a representation and decide the most opportune time to use the representation to extend

students' understanding. Abell (2007) noted that research investigating teacher representations of science content is not well represented in science education literature.

A study by Mastrilli (1997) investigated the use of analogies among eight in-service biology teachers and noted teacher participants implemented 151 analogies during the 40 class periods observed. Mastrilli (1997) separated analogies into five categories: (1) simple or descriptive, (2) compound, (3) spontaneous, (4) example, and (5) visual. Teacher participants most commonly implemented simple/descriptive analogies described by the researcher as either simile (72/151) or metaphor (66/151) (Mastrilli, 1997). Most teachers reported using analogies spontaneously as representations of concepts during teaching to maintain student interest or make connections between content and students' experience.

Several studies investigated science teachers' use of models in teaching high school chemistry. Harrison and Treagust (2000) described models implemented by teachers as a simplified representation of an abstract concept making the central features of the concept explicit and visible for students rather than using models as a means of generating explanations and testing predictions. A study by Van Der Valk, Van Driel, and De Vos, (2007) investigated common characteristics of models used in current scientific research to develop recommendations for the implementation of models in science curricula. The researchers posit teacher conceptions of models and modeling be broadened to perceive models as problem solving and decision making tools rather than as simplified representations of abstract concepts (Van Der Valk et al. 2007). Two studies conducted by Justi and Gilbert (2002a, 2002b) investigated the use of models for teaching science among elementary and secondary students in Brazil and the UK. Students'

understanding of models was divided into three categories: (1) understanding of major scientific and historical models as well as the scope and limitations of the models, (2) understanding of the nature and role of models in scientific inquiry, and (3) understanding of how to create and test their own models. The researchers noted 90 percent of teacher participants categorized the purpose for models within their teaching in the first category, as a teaching tool representing abstract concepts for students (Justi & Gilbert, 2002b). Few teachers recognized the importance of models as a learning tool through which students are able to engage in constructing models to illustrate concepts or test predictions about concepts represented by the models (Justi & Gilbert, 2002a, 2002b). Two studies conducted by Van Driel and Verloop (1999, 2002) investigated science teacher knowledge of models and modeling and found knowledge of models and modeling as a learning tool for students was noted to be low among the participants. Teachers placed greater emphasis on the content of models as a concrete representation of an abstract concept rather than model construction as a powerful learning activity for students indicating limited knowledge of students' conceptions of models (Van Driel & Verloop, 1999; Van Driel & Verloop, 2002). Overall, studies investigating teacher use of models and modeling indicated teachers perceived models as simple, concrete representations rather than as student generated tools for making and testing predictions of scientific concepts.

Knowledge of instructional strategies. Magnusson et al. (1999) defines two sub-categories for science teacher knowledge of instructional strategies: (a) subject-specific knowledge, addressing the knowledge of strategies including investigations and demonstrations appropriate for teaching a subject in science (e.g., biology, chemistry, or

physics); and (b) topic-specific knowledge appropriate for teaching a specific topic in science (e.g., genetics, cell biology, diffusion, osmosis). Topic-specific PCK references the knowledge necessary for integrating topic-specific content knowledge with teacher knowledge of learners, likely misconceptions and appropriate representations and instructional strategies to make the knowledge understandable for students.

A study by Trigwell, Prosser, and Waterhouse (1999) investigated the relationship between experienced teachers' approach to teaching and students' approach to learning. They found a teacher-centered, information-transmission approach to teaching was strongly associated with a surface approach to learning among students. In contrast, a student-centered, conceptual change approach to teaching stimulated the use of deeper learning strategies among students (Trigwell et al. 1999). Hence, the researchers posit a relationship exists between the nature of instructional strategies implemented by the teacher and the depth of students' learning (Trigwell et al. 1999). Investigating a constructivist approach to teaching, Borko and Putnam (1996) found teacher support to be critical for students' learning through constructivist, student-centered instructional strategies. The perception of the role of the teacher must be that of a facilitator for students' knowledge rather than that of a transmitter of knowledge. Hence, teachers must be aware of instructional strategies that actively engage students and promote higher order thinking and cognitive processing (Borko & Putnam, 1996).

Taraban, Box, Meyers, Pollard, and Bowen (2007) investigated the effectiveness of active-learning laboratory investigations for topics in high school biology developed through collaboration between high school biology teachers and university faculty. The researchers compared teacher learning with student achievement. The program involved

six high school biology teachers engaged in a partnership with a university to incorporate an inquiry-oriented, student-centered instructional approach focused on laboratory investigations. Study findings indicate teachers engaged in the program: (a) enhanced knowledge of learners, (b) expanded knowledge of instructional strategies, (c) increased the implementation of inquiry-oriented instruction, and (d) reduced worksheets and cookbook investigations. The teachers participating in the study significantly reduced reliance upon traditional instruction, largely focused on the transmission of information through lecture (Taraban et al. 2007). A student questionnaire data indicated a significant increase in students' content knowledge and knowledge of science process skills resulting from the expansion of teacher knowledge.

Van Driel, Verloop, & de Vos (1998) investigated experienced chemistry teachers' PCK for teaching chemical equilibrium. Initially, researchers focused on teachers' PCK for teaching chemical equilibrium by engaging teachers with investigations, representations, and assignments associated with teaching the topic and discussions of authentic students' responses to assignments (Van Driel et al. (1998). During the study, teachers promoted conceptual change among students by discussing results of reversible chemical reactions and challenging students' conceptions of chemical reactions through small group discussions. Van Driel et al. (1998) encouraged teachers to evaluate analogies and metaphors used in the past to explain chemical equilibrium and evaluate these representations in light of students' ideas and responses to investigations, activities, and assignments focused on stimulating conceptual change. Questionnaire responses at the close of the study indicated a deepening of teachers' knowledge of learners, representations, and instructional strategies, as well as teacher

gains in terms of content knowledge for teaching chemical equilibrium (Van Driel et al. 1998).

Science education literature indicates the development of teachers' PCK in terms of knowledge of representations and instructional strategies results from teaching experience (Justi & Gilbert, 2002a, 2002b; Taraban et al. 2007; Van Der Valk et al. 2007; Van Driel et al. 1998; Van Driel & Verloop, 1999, 2002). However, teaching experience alone cannot account for this aspect of teacher knowledge. A common theme within the studies cited in this section is the importance of expanding teacher knowledge through professional development to support the implementation of new instructional strategies and representations (Schwarz et al. 2009; Taraban et al. 2007; Van Der Valk et al. 2007; Van Driel & Verloop, 1999, 2002; Van Driel et al. 1998).

There is a notable gap within science education research among the studies discussed within this section. For instance, studies investigating representations such as analogies (Mastrilli, 1997) and teacher use of models (Harrison & Treagust, 2000a; Justi and Gilbert 2002a, 2002b; Van Der Valk et al. 2007; Van Driel & Verloop, 1999, 2002) investigated teacher implementation of analogies and models in general terms; these studies did not investigate teachers' use of analogies and models for teaching specific topics in science.

The Van Driel et al. (1998) is the only study to investigate the topic-specific nature of teacher knowledge by examining experienced chemistry teacher knowledge for teaching chemical equilibrium. Hence, little is known about the nature of experienced teacher knowledge of representations and instructional strategies for teaching a specific topic in science. Taraban et al. 2007 investigated teacher knowledge of inquiry-oriented

instructional strategies in general terms, not focusing on any one topic in science. The general focus of the overwhelming majority of these studies ignores the nature of experienced teacher PCK or how the teachers drew upon their knowledge to engage students with representations and instructional strategies for teaching a specific topic in science. Understanding the nature of topic-specific teacher knowledge of representations and instructional strategies provides greater insight into an understanding of how teachers draw upon their knowledge, integrate knowledge of content with their pedagogical content knowledge, and the knowledge of learners, representations, strategies, assessments, and curricula to make specific topics understandable to students.

Knowledge of students' understanding of science. Magnusson et al. (1999) defined this component of PCK as pertaining to requirements for learning, potential learning difficulties associated with content, and prior knowledge or misconceptions about content held by students. Abell (2007) reported research in the area of students' understanding of science was concentrated on teacher knowledge of alternate conceptions of science, teacher images of ideal science students, and general views of science learning (p. 1127).

A critical aspect of science teacher PCK is the ability to predict potential student learning difficulties with content. Driver, Squires, Rushworth, and Wood-Robinson (2003) posit students develop conceptions of the natural world through their experiences, observations, and interactions with peers. Hence, students are not blank slates, instead, they bring into the classroom their prior knowledge and experiences which may be inaccurate perceptions of the natural world and interfere with learning (Driver et al. 2003). Leach and Scott (2003) reported that it is necessary for teachers to understand the

knowledge students bring into the classroom to accurately predict potential learning difficulty with content.

Wallace and Kang (2004) investigated teacher beliefs in relation to the implementation of inquiry-based instruction and found teacher beliefs about students' limitations, maturity, or learning difficulties with content influence the implementation of inquiry-based instruction. In addition, Wallace and Kang (2004) noted teachers held competing belief sets; belief sets which constrained inquiry-based teaching were identified as beliefs about students, while beliefs about quality instruction supported the inclusion of inquiry-based instruction. Cohen and Yarden (2009) investigated 59 Israeli science and technology teachers' PCK with regards to the topic of the living cell. The study investigated teachers' PCK in light of a curricular change mandating that the cell topic be taught longitudinally, integrating the concept with students' understanding of multicellular organisms as consisting of single cells functioning as tissues, organs, or organ systems to maintain life. Study participants noted even though students were familiar with the concept of cells as microscopic and living entities, they were likely to describe the cell as flat or two-dimensional and experience difficulties perceiving the cell as a three-dimensional structure (Cohen & Yarden, 2009). One of the teachers noted her students thought cells had lungs, a misconception previously reported by Dreyfus and Jungwirth (1988). Cohen and Yarden (2009) note teachers experienced conflicts between their beliefs about the importance of the cell topic and the actual integration of the topics related to the cell in classroom practice. Teachers were very concerned about students' perception of the cell as a three-dimensional entity and were found to have no PCK for the integration of biological phenomena at the macro-level with their explanations of the

cell at the micro-level (Cohen & Yarden, 2009). Teachers also failed to make connections between various organizational levels (e.g., molecular, cellular, tissue, organ, organ system, organism) when teaching the concept of cells. Hence, the teachers' concerns about potential students' learning difficulties associated with the cell resulted in the teachers dedicating less time to teaching the cell at the macro-level (e.g., the function of cells within tissues, organs, organ systems, and organisms) and more time to teaching the cell topic at the micro-level. Thus, teacher beliefs resulted on a focus for teaching the cell at the micro-level and acted as a constraint for teaching the cell concept at the macro-level and making relevant connections between the nature and function of the cell and macroscopic examples of the cell. A study by Cronin-Jones (1991) investigated the implementation of changes in curriculum by experienced teachers and identified the perception held by the teacher about how students learn, students' learning abilities, and the perception of the role of the teacher to be major factors in the implementation of the curriculum. Hence, teacher beliefs about students as science learners are important factors in determining teacher actions in the classroom (Cronin-Jones, 1991).

Jones, Carter, and Rua (1999) investigated the roles that students' conceptual understanding of science play in promoting the development of teacher knowledge. Study findings indicated teachers did not take steps to reveal students' understanding of science concepts and were shocked by the misconceptions students held. After investigating student learning, teachers reported greater motivation to enhance their understanding of science content, reconsider their teaching practices to include inquiry-based instructional strategies, and place greater emphasis upon students' prior knowledge of science concepts (Jones et al. 1999).

Athanassios and Komis (2003) posit that students possess an incoherent system of beliefs and intuitions about the physical world which are incompatible with scientific theories and derived from their everyday experience. In a study investigating the inclusion of inquiry-based instruction within the Greek Science Curriculum, researchers investigated the effectiveness of a constructivist approach to teaching physics in terms of students' understanding of Newton's Laws. Findings indicated an improvement in students understanding of Newton's Laws when teachers demonstrated greater understanding of students as science learners. Teacher ability to interpret students' statements and actions and respond by adapting teaching to meet students' needs was an important factor in teachers' progression from a teacher-centered to a student-centered teaching approach.

Abell (2007) noted that research investigating teacher knowledge of science learning "employed a wide range of methods and lacked cohesion in terms of the research questions addressed" (p. 1128). The studies indicate teachers are often unaware of the prior knowledge held by their students or place minimal importance on students' inaccurate conceptions of scientific principles. Students' ideas are important considerations when teachers consider the teaching approach for a specific scientific concept. Students bring prior experiences, knowledge, and habits of mind into the classroom which influence how they interpret, understand, and respond to teacher actions. Teacher understanding of students as learners is critical for effective teaching and learning (Ball & Cohen, 1999). Few studies dealt with teacher knowledge of students as learners. Most of the studies reviewed for this section focused on the influence of instructional strategies initiated by the teacher upon students' learning. However, the

studies did not focus on the nature of teacher knowledge of students as learners and how that knowledge was drawn upon for teaching a specific concept in biology. Hence, there is a significant gap in the science education literature in this regard.

Knowledge of science assessment. Magnusson et al. (1999) describe the knowledge of assessment in science as conceptualizing the scientific literacy of their students to “inform their decision-making relative to classroom assessment of science learning for specific topics” (p. 108). Teachers must know what to assess and the assessment methods to employ to measure the knowledge of that topic held by students (Magnusson et al. 1999). Summative assessments evaluate the knowledge held by students on a specific topic and measure student learning following the completion of a unit in science. Formative assessments occur during instruction and provide the teacher with insight into students’ prior knowledge before instruction or conceptual understanding of a topic in science during instruction. Through formative assessment practices, teachers provide feedback to students in an effort to redirect their thinking and/or stimulate self-assessment of their own work.

Atkin, Black, and Coffey, (2002) identify a framework for formative assessment guided by three considerations: (1) identification of the learning and performance goals, (2) assessment of students’ current level of understanding or students’ self-evaluation of their work, (3) assisting students with the development of strategies and skills to help them reach their goals (NRC, 2002).

Abell (2007) posits “knowing what assessment methods teachers use does not provide insight into how assessment is enacted” (p. 1132). To gain insight into formative assessment and how it is enacted in the science classroom, Cowie and Bell (1999) and

Bell and Cowie (2001) conducted a two-year study investigating formative assessment practices among ten New Zealand science teachers. Cowie and Bell (1999) noted teacher participants utilized two forms of formative assessment: (1) planned or formal formative assessment and (2) interactive or informal formative assessment. Planned formative assessment was described by researchers as a planned event (e.g., brainstorming, survey, pretest) to assess understanding among the entire class often at the beginning of a unit; teachers used feedback from this assessment to inform their teaching during the unit (Cowie & Bell, 1999). Interactive formative assessment took place during the lesson, involved teacher-student interactions, observations of student-student interactions, was not planned, occurred during instruction, and embedded within teaching and learning activities (Cowie & Bell, 1999). Hence, interactive formative assessment was predicated upon teacher observations, interactions with students, students' questions, and other observations of students made during teaching. Teaching experience was identified as a major factor in terms of teachers' ability to accurately observe and interpret students' behaviors, interactions, and questions to assess students' understanding of concepts during teaching (Cowie & Bell, 1999). Existing and developing assessment practices among the teacher participants were investigated during a two-year research project (Bell & Cowie, 2001). Researchers described formative assessment as "the process used by teachers and students to recognize and respond to student learning in order to enhance learning during the learning" (Bell & Cowie, 2001, p. 536). Working with teacher participants, researchers identified nine characteristics of formative assessment: (1) responsive to students' learning needs, (2) identifies sources of evidence for students' understanding, (3) described as a tacit process, (4) uses professional knowledge and

experiences, (5) functions as an integral part of teaching and learning, (6) implemented by both teachers and students, (7) driven by the goals and purposes for instruction, (8) results in changes in teaching and learning strategies, and (9) identifies dilemmas faced by teachers in accurately interpreting students' responses. The researchers posit the value in documenting the characteristics of formative assessment lies in making the nature of a largely tacit process more visible and explicit for teachers (Bell & Cowie, 2001). The studies by Cowie and Bell (1999) and Bell and Cowie (2001) underscore the importance of continuous assessment for learning rather than assessment of learning.

Liew and Treagust (1998) used action research conducted by the first author to investigate the use of the Predict-Observe-Explain (POE) instructional strategy for assessing Australian students' knowledge of physics concepts in terms of: (a) prior knowledge of concepts in physics before instruction, (b) conceptual understanding during instruction, and (c) learning progress during instruction. Study findings indicate the POE strategy is effective in determining students' knowledge of concepts prior to instruction and using students' feedback to identify potential learning difficulties and adjust instruction (Liew & Treagust, 1998). By implementing the POE strategy with each investigation, teachers are able to assess students' conceptual understanding of physics concepts, align instruction to student needs, and monitor students' progress throughout the course.

Ruiz-Primo and Furtak (2006) investigated formative assessment within the context of scientific inquiry and within classrooms of four middle school physical science teachers. The goal of the study was to capture the nature of informal formative assessment to assist other teachers with assessment practices through prospective teacher

preparation and professional development for inservice teachers. The researchers investigated informal formative assessments including student-teacher interactions, whole class discussions, small group interactions, or student-student interactions which were implemented by teachers during instruction; next, informal assessments were compared to student learning. Researchers found students performance on embedded assessments within lessons was enhanced when teachers implemented formative assessment techniques consisting of four steps: (1) the teacher poses a question, (2) the student responds, (3) the teacher recognizes the student response, and (4) the teacher uses the information to support student learning (Ruiz-Primo & Furtak, 2006, p. 207). In contrast, students of teachers who implemented a three-step cycle, (a) the teacher poses a question, (b) the student responds, and (c) the teacher evaluates the student's response, performed at a lower level on embedded assessments (Ruiz-Primo & Furtak, 2006, p. 207). The study underscores the importance of formative assessment during the lesson as a means for teachers to adjust instruction, address students' learning difficulties with content, and support students' learning. The use of formative assessment to assess student knowledge before instruction and monitor students' progress during instruction was a common theme throughout these studies.

Morrison and Lederman (2003) investigated classroom routines of four exemplary science teachers to determine whether any diagnosis of students' prior knowledge or analysis of students' written work occurred before or during the teaching of a specific science concept. Although teacher participants noted the importance of identifying students' prior knowledge before teaching, even the most experienced of the participants indicated he experienced difficulty when pre-assessing students' ideas. Hence,

participants did not engage in pretesting, interviewing, or pre-writing to reveal students' prior knowledge of concepts (Morrison & Lederman, 2003). Participants used informal questioning to reveal students' thinking prior to teaching. However, researchers noted the questions were largely recall in nature and did not reveal students' understanding and personal beliefs about the concept; only the most experienced teacher used probing questions to reveal students' thinking (Morrison & Lederman, 2003). Bol and Strage (1996) investigated the connection between the learning goals for students and teacher assessment practices among ten high school biology teachers. During the study, the teachers emphasized their desire for students to develop an interest in biology, to understand real-world applications for biology, to develop higher order study skills, and to employ critical thinking skills (Bol & Strage, 1996). However, teacher assessment practices revealed that 52% of test questions and 53% of practice assessments required only basic knowledge, while only 5% of test questions and 4% of practice assessments required students to apply their knowledge (Bol & Strage, 1996). Researchers noted that teacher interviews revealed a lack of awareness regarding the disparity between the goals for students' learning and the formative assessments implemented during teaching.

The studies cited within this section reveal a lack of teacher understanding of formative assessment as a means of informing instruction and meeting learning goals for students. The studies investigated the implementation of formative assessments in general and do not focus on teacher use of formative assessments for teaching specific concepts in science. Ongoing assessment of students' conceptual understanding during teaching is an important aspect of effective instruction as indicated in the studies reviewed for this section. However, the nature of experienced teachers' knowledge of formative

assessments designed to reveal students' prior knowledge before instruction and conceptual understanding during instruction is absent from the literature. There are important benefits for experienced and prospective teachers resulting from investigating the design, implementation, and interpretation of formative assessments to evaluate student learning and inform teaching of specific topics in science. There is little research examining teachers' knowledge of assessment strategies in general.

Knowledge of science curriculum. Magnusson et al. (1999) identified two types of curricular knowledge as: (1) the knowledge of mandated goals and objectives (e.g., district, state and national standards) and (2) knowledge of specific curricular programs and materials. Abell (2007) reported curricular studies typically ask teachers to rank curricular goals from most to least important rather than investigate the knowledge of curriculum held by the teachers.

Avery and Carlsen (2001) investigated the roles of curriculum makers and curriculum users by engaging science teachers in the formation of a professional learning and teaching community through which the development and implementation of their Environmental Inquiry project was realized. During the design of the project, teachers were curriculum makers; however, with the implementation of the curriculum, the teachers became curriculum users. Avery and Carlsen (2001) noted that as curriculum users, the teachers negotiated the meaning and purpose of innovations within the curriculum and adapted the curriculum to address the curricular mandates within their schools. Researchers found by engaging teachers with both the development and implementation of curriculum, teachers gained a better understanding of the goals of the

curriculum and the new teaching practices or instructional models necessary to support student learning within the context of the curriculum.

Schneider and Krajcik (2000) investigated the implementation of inquiry-based science instruction into eighth grade physical science within the context of a large urban public school district. The researchers posit teachers' ability to enact inquiry-based instruction successfully ultimately depends upon supporting teachers' understanding and implementation of new instructional practices which support student learning through inquiry; hence, teacher participants were supported with a two-week summer institute, three Saturday sessions, and a weekly in-class support program provided by university and district personnel (Schneider & Krajcik, 2000). Study findings indicate the support provided to teachers to implement inquiry-based instructional strategies into their curriculum enhanced teachers' understanding of topic-specific ideas within the lesson and the strategies (PCK) necessary to engage students with learning the concepts (Magnusson et al. 1999; Schneider & Krajcik, 2000).

Jones and Eick (2007) investigated the changes in PCK of two middle school science teachers as they implemented a kit-based inquiry curricular reform program. Both teachers made changes in their teaching approach; one moved away from using only open-ended inquiry and engaged students with journaling and performance assessments. The other teacher moved from a teacher-centered to a student-centered instructional approach and engaged students with cooperative learning and guided inquiry (Jones & Eick, 2007). The successful implementation of the kit-based inquiry program by the teacher participants resulted from ongoing professional development providing both training and support for the teachers.

Furio, Vilches, Guisasola, and Romo, (2002) investigated the views of the goals of secondary science education held by Spanish teachers. Changes in curricular trends in the Spanish science education placed greater emphasis upon scientific literacy for all students rather than focusing upon students' formal knowledge of chemistry and physics. Furio et al. (2002) used questionnaires to reveal teacher perception of the goals and purposes for teaching science, curricular knowledge, concerns about implementing changes within the science curriculum, and necessary support for teacher implementation of curricular changes. Teachers' responses indicated the science curriculum should focus on the laws and principles of science with the goal of preparing students for higher education rather than motivating students' interest in science and achieving scientific literacy for all students. The researchers noted significant support and training would be necessary to prepare teachers to implement the new curriculum. Hence, the findings of Furio et al. (2002) are in line with those of Schneider and Krajcik (2000) in emphasizing the importance of teacher preparation and support for the implementation of curricular changes.

Kesidou and Roseman (2002) examined middle school curricular programs to determine if programs supported ideals identified in the *National Science Education Standards* and to identify the strengths and weaknesses within each of the nine programs examined. Findings were organized into three categories. First, reviewers determined the middle school curricular programs exhibited a lack of focus and did not make connections between key ideas found in multiple units (Kesidou & Roseman, 2002). Second, the instructional design did not focus on identification of students' prior knowledge, and did not suggest strategies for teachers to address student misconceptions

(Kesidou & Roseman, 2002). Third, teachers' guides were insufficient in suggesting instructional strategies to scaffold students' learning and interpreting students' responses (Kesidou & Roseman, 2002). The study indicates there is little emphasis on teacher knowledge or support for teacher learning in the curricular program which is a serious flaw undermining effective science teaching and learning (Furio et al. 2002; Jones & Eick, 2007; Kesidou & Roseman, 2002; Schneider and Krajcik, 2000).

The theme emerging from these studies is the importance placed by researchers on teacher perceptions of the goals and purposes of the science curriculum. However, little emphasis was placed upon the knowledge of curriculum held by teachers and how that knowledge was drawn upon when teaching specific topics in science. For example, the studies did not investigate teacher knowledge of the horizontal and vertical curricula in terms of teaching a specific topic in science. Teacher knowledge of curriculum was not clarified in the studies and the manner in which teachers drew upon their knowledge of curriculum and integrated that knowledge with other components of PCK was missing from the literature.

Knowledge integration. In a study of prospective science teachers, Davis (2003) investigated the development of PCK through the perspective of knowledge integration described as a means of "differentiating, integrating, and restructuring ideas" (p.21). Davis (2003) suggests prospective teachers enhance their knowledge of teaching and develop PCK through teaching experience and reflection upon their practice. As prospective teachers gain teaching experience and reflect upon their practice, they are able to identify weaknesses and teaching and consider new understandings of learners, representations, instructional strategies and assessments. Prospective teachers integrate

new knowledge of learners, representations, instructional strategies, and assessment with their existing knowledge to develop a unique form of knowledge (PCK) for teaching science.

In terms of the PCK of experienced teachers, Hashweh (1985) conceptualized PCK as topic-specific knowledge developed by teachers with experience in teaching specific topics. This conceptualized knowledge results from the integration of knowledge of students as learners, their prior knowledge, potential learning difficulties associated with specific content, and appropriate representations and instructional strategies to effectively engage students and enhance their conceptual understanding of the concept (Hashweh, 1985). Fernandez-Balboa and Stehl (1995) asserted PCK results from the integration of different components of teacher knowledge. Van Driel et al. (1998) posited PCK is topic-specific and includes knowledge of subject matter, learners, representations, instructional strategies and assessments for teaching specific topics in science. Calderhead (1996) noted teacher knowledge has several origins including teaching experiences, formal teacher preparation, and ongoing professional development. Loughran, Mulhall, and Berry (2004) support the description of PCK as highly integrated knowledge and described teacher PCK as the “teachers’ grasp of, and response to, the relationships between knowledge of content, teaching, and learning in ways that attest to notions of practice as being complex and interwoven” (p. 370).

Park and Oliver (2008) expanded upon the theme of knowledge integration to investigate the continued development and integration of the components of PCK among experienced teachers seeking National Board Certification. Findings indicated teachers continually integrate new knowledge for teaching science into their existing PCK. New

knowledge, developed through reflection on classroom experiences with learners, professional development, and collaboration with colleagues, is added and integrated into existing knowledge (Loughran et al. 2004). Verloop, Van Driel, and Meijer (2001) identify teacher practical knowledge as all of the knowledge, beliefs, and intuitions held by the teacher resulting from teaching experience, formal preparation, and ongoing professional development and describes this knowledge as “inextricably intertwined” (p. 446). As new ideas are added and reconciled with existing ideas, teacher knowledge becomes increasingly integrated and develops into a specialized and sophisticated form of knowledge for teaching (Davis, 2000, 2003; Fernandez-Balboa and Stehl (1995); Hashweh, 1985; Loughran et al. 2004; Park & Oliver, 2008; Shulman, 1986; Verloop et al. 2001).

Studies investigating the nature of knowledge held by experienced teachers for teaching specific topics in science is largely absent from the literature. The highly integrated nature of the PCK of experienced teachers and the manner in which they draw upon this knowledge to reveal students’ prior knowledge of topics, address students’ misconceptions, engage students with representations and instructional strategies, and monitor students conceptual understanding of topics can only be observed in teacher practice. The studies cited in this section posit the development of PCK among prospective and experienced teachers is predicated upon their integration of knowledge for teaching. However, the studies do not investigate topic-specific PCK held by experienced science teachers for teaching a specific topic. The goal of my study is to better understand the knowledge integration of the experienced teachers’ PCK for teaching for teaching a specific topic in science.

Topic-specific PCK for Teaching Diffusion and Osmosis

Shymansky, Woodworth, Norman, Dunkase, Matthews, and Liu (1993) note that teacher PCK in terms of knowledge of students as learners can be improved by studying the structure and evolution of students' ideas about specific topics in science. Van Driel et al. (1998) note science education research on science teachers' PCK has focused on the nature and development of PCK rather than on the PCK necessary for teaching specific topics in science. Hence, the purpose of this section is to focus upon the nature of PCK held by experienced biology teachers for teaching diffusion and osmosis. The section is divided into two sections: (1) a review of the literature investigating practitioner knowledge for teaching osmosis and diffusion and (2) a review science education literature examining teacher PCK for teaching diffusion and osmosis.

Review of Practitioner Literature for Teaching Osmosis and Diffusion

Friedrichsen and Pallant (2007), Marek, Cowan, and Cavallo (1994), Marvel and Kepler (2009), Odom (1995), Villani, Dunlop, and Damitz (2007), Zrelak, and McCallister, (2009), and Zuckerman (1993) identify the importance of students' conceptual understanding of diffusion and osmosis and note these concepts form the basis for students' understanding of biological processes. Hence, conceptual understanding of diffusion and osmosis provides the foundation for understanding complex processes such as: photosynthesis, cellular respiration, and the maintenance of homeostasis in living cells and systems. The authors also note the complex and integrated nature of diffusion and osmosis which draws from chemistry (e.g., relative concentrations dissolved solids), physics (e.g., the particulate nature of matter and random molecular motion), and biology (e.g., the nature of semipermeable cell membranes). Friedrichsen and Pallant (2007), Marek et al. (1994), Odom (1995), and Zuckerman (1993) identified common

misconceptions held by high school and college students regarding diffusion and osmosis. The authors provide teachers with an awareness of students' misconceptions and explanations of how that prior knowledge, if not addressed, can constrain learning. Thus, practitioner journals provide an exceptional source of knowledge of learners, content, representations, and instructional strategies for teachers.

In general, this literature noted students often struggle with understanding diffusion and osmosis because they do not perceive random molecular motion as the driving force for the processes or understand the importance of the relative concentrations of dissolve solids within two solutions separated by a semipermeable membrane. Suggestions for supporting the development of students' conceptual understanding of diffusion and osmosis are provided by several of the authors.

Friedrichsen and Pallant (2007), Marvel and Kepler (2009), Villani, Dunlop, and Damitz (2007), and Zrelak and McCallister (2009) suggest the implementation of a 5E instructional sequence (Bybee, 1997), for teaching osmosis and diffusion. The authors suggest teachers challenge students with an exploration of concepts prior to generating an explanation and extend knowledge by challenging students to apply their knowledge to novel scenarios. As students investigate the nature of membranes and the direction of osmosis, they begin to make sense of the processes and understand the development of a concentration gradient and the forces which determine the direction of osmosis. These articles provide an important knowledge source for prospective and experienced teachers. The authors are typically high school teachers sharing their ideas and experiences with fellow practitioners. The articles represent important insight into the knowledge and practice of secondary teachers by defining concepts as well as identifying and describing

representations, demonstrations, investigations, and experiments investigating specific topics in science.

Review of Science Education Research Literature Examining Teaching and Learning Related to Diffusion and Osmosis .

Magnusson et al. (1999) posit PCK is the understanding held by the teacher of how particular subject matter topics, problems and issues should be organized, represented, and adapted and taught to make specific topics in science understandable for students. Diffusion and osmosis are critical concepts in biology and are implicated in explaining biological concepts associated with the movement of substances along a concentration gradient, the maintenance of homeostasis in cells, and the movement of water and dissolved materials across a semipermeable cell membrane (Christianson, & Fisher, 1999; Odom, & Barrow, 2007; Odom & Barrow, 1995; Odom & Kelly, 2001; Tekkaya, 2003; Zuckerman, 1993).

A study by Zuckerman (1993) investigated problem-solving within the context of concepts related to osmosis among secondary students excelling in science. Findings indicated many study participants held misconceptions about osmosis. Only six participants were able to solve the problem correctly; however, during interviews, several students revealed misconceptions about osmosis even though they were able to solve the problem correctly (Zuckerman, 1993). The eight misconceptions made explicit by the study included: (1) water anthropomorphically osmoses to equalize either the amount or relative concentration, (2) different amounts of water rather than different concentrations drive osmosis, (3) water cannot osmose against a pressure gradient, (4) the rate of osmosis is constant, (5) water molecules cease moving across a membrane at osmotic

equilibrium, (6) the hydrostatic pressures across the membrane must be equal as osmotic equilibrium, (7) the amounts of water across the membrane must be equal at osmotic equilibrium, and (8) the concentrations of water across the membrane must be equal at osmotic equilibrium (Zuckerman, 1993). Study findings indicate misconceptions four and eight (the rate of osmosis is constant, and the concentrations of water across the membrane must be equal at osmotic equilibrium) effectively blocked students from solving the problem accurately (Zuckerman, 1993). This study emphasizes the importance of students' prior knowledge and encourages opportunities for students to explain the direction of water movement during osmosis to make students' conceptual understanding explicit. Hence, Zuckerman (1993) suggests that teachers evaluate students' prior conceptions of osmosis before teaching the concepts.

Odom and Barrow (1995) and Odom and Barrow (2007) investigated students' misconceptions about diffusion and osmosis through the Diffusion and Osmosis Diagnostic Test (DODT). The DODT was administered to high school and college biology students as a pre-test to make misconceptions explicit and as a post-test to reveal students' conceptual understanding of the phenomena (Odom & Barrow, 1995; Odom & Barrow, 2007). Study findings identified 20 misconceptions held by both high school and college biology students related to tonicity, membrane function, particulate nature of matter, random molecular motion, diffusion as a process, osmosis as a process, and the influence of life processes on diffusion and osmosis (Odom & Barrow, 1995). Therefore, the study illustrates the conceptual difficulty of the topic and the need to better understand the processes of diffusion and osmosis and how these processes influence the maintenance of homeostasis and the production of cellular energy among all life forms.

Christianson and Fisher (1999) investigated students' learning related to diffusion and osmosis within the context of a college biology course; students were taught with three different instructional approaches including: (1) traditional instruction, (2) traditional instruction and a laboratory/discussion group, and (3) student-centered instruction in which constructivist instructional strategies were implemented. The DODT (Odom & Barrow, 1995) was implemented as a pre and post test. Students in the student-centered constructivist group out-performed the other two groups indicating a strong conceptual understanding of osmosis and diffusion.

Odom and Kelly (2001) investigated students' learning via traditional instruction of concepts related to diffusion and osmosis within the context of three forms of student-centered instruction including: concept mapping, the learning cycle, and an integration of concept mapping and the learning cycle. The researchers implemented the DODT (Odom & Barrow, 1995) as a pre and post test; study findings indicated students taught through the learning cycle and concept mapping out performed students exposed only to traditional instruction (Odom & Kelly, 2001). However, students showing the most significant gains on the DODT (Odom & Barrow, 1995) were students taught with a combination of concept mapping and the learning cycle (Odom & Kelly, 2001). Similar results were noted by Takkaya (2003) in a study examining the effectiveness of combining conceptual change and concept mapping strategies on students understanding of diffusion and osmosis. Forty-four ninth grade students in two separate classes within the same urban high school were involved in the study; one class received traditional, teacher-centered instruction while the other class received student-centered instruction addressing students' misconceptions and engaging students with conceptual change and

concept mapping strategies (Takkaya, 2003). The DODT (Odom & Barrow, 1995) served as a pre and post test; findings identified misconceptions similar to those noted by the Odom and Barrow (1995, 2007) studies (Takkaya, 2003). Study findings indicated the difficulty involved in eliminating students' misconceptions associated with diffusion and osmosis; the average percentage of students in the control group showed gains in understanding on the DODT of 19.1% whereas, in the experimental group the average percent of students showing increased comprehension was 31.6% (Takkaya, 2003). The interdisciplinary nature of the concept was given as the reason for the difficulty involved in eliminating students' misconceptions. Diffusion and osmosis integrate concepts related to physics, chemistry, and biology and understanding these concepts involves an understanding of the nature of solutions, random molecular motion, membrane permeability, relative concentrations of dissolved solids, and concentration gradients (Odom & Barrow, 1995, 2007; Takkaya, 2003).

There are several themes noted which emerged from these studies. First, diffusion and osmosis were selected as the concepts to be taught in each of the studies for four reasons: (1) the interdisciplinary nature of the concepts requires students to integrate knowledge of physics, chemistry, and biology; (2) the concepts were challenging for students to learn; (3) the concepts are challenging for teachers to teach; and (4) the concepts form a basis for understanding the nature of the cell, the maintenance of homeostasis, and energy production in the cell. Second, high school and college students held similar misconceptions related to diffusion and osmosis. Third, the DODT (Odom & Barrow, 1995) was used to evaluate student learning in all of the studies with the exception of Zuckerman (1993). Fourth, the most effective forms of instruction were

student-centered and involved constructivist strategies including the learning cycle, making and testing predictions, and concept mapping.

Another important theme noted among these studies is the focus on student learning rather than teacher knowledge. Teacher knowledge is only addressed indirectly in terms of knowledge of potential misconceptions, representations, and instructional strategies; there were no teacher interviews or evaluations of teacher content knowledge, pedagogical knowledge, or pedagogical content knowledge. Hence, there is a significant gap in the literature in terms of the knowledge of experienced teachers for teaching specific concepts such as diffusion and osmosis.

Gaps within the Literature

The studies I reviewed for this literature review revealed the majority of studies investigating PCK were concerned with the development of PCK among prospective teachers within the context of an alternative certification program. A limited number of studies did focus on the general nature of PCK among experienced teachers. Several studies were reviewed which described the nature of knowledge for teaching specific topics in mathematics as packaged. The packaged knowledge for teaching specific topics included: content knowledge as well as the knowledge of learners, representations, instructional strategies and assessments for teaching specific mathematical concepts. These studies underscored the integrated nature of knowledge held by experienced mathematics teachers. However, only one study was found in the science education literature which focused on the nature of PCK held by experienced teachers for teaching specific concepts in science. Most of the studies reviewed in science education literature

were general in nature and did not focus on characteristics of topic-specific PCK necessary for teaching specific concepts in science.

The literature reviewed for this section revealed a lack of research focused on the PCK held by experienced teachers for teaching a specific topic in science. For example, few studies were found investigating the orientation of experienced science teachers for teaching science and how goals and purposes, perceptions of teacher and students' roles, and ideal images of teaching informed instructional decisions and teaching practice. Few studies were found which examined the nature of PCK held by experienced science teachers for teaching a specific topic in science and how their knowledge informed their teaching in terms of: (a) use of representations and instructional strategies, (b) understanding of learners and potential difficulties, (c) implementation of formative assessments to reveal students' prior knowledge and conceptual understanding, and (d) selection of lesson content and sequence of instruction. This study will address these gaps.

The majority of studies were focused on prospective teachers. Few studies have been conducted which investigate the knowledge and practice of experienced teachers. Even fewer studies are focused on the PCK held by experienced teachers for teaching specific concepts or topics in science. A number of researchers have asserted that teacher PCK develops as a result of teaching experience (Van Der Valk et al. 2007; Van Driel et al. 1998; Van Driel & Verloop, 1999, 2002). Van Driel and Verloop (2002) note the need for additional studies investigating the integration of teacher knowledge of representations and instructional strategies with knowledge of students' conceptions of science.

In reviewing the science education literature, there is little emphasis on the knowledge and practice of experienced teachers. Little work has been devoted to investigating the PCK of experienced teachers and how that knowledge influences their instructional decisions and teaching practice. For instance, studies conducted by Christianson and Fisher (1999), Johnstone and Mahmond (1980), Odom and Barrow (1995), Odom and Barrow (2007), Odom and Kelly (2001), and Zuckerman (1993) examined students' conceptual understanding of osmosis and diffusion. However, the studies did not examine the topic-specific PCK held by the teachers; hence, there is little known about the nature of teacher PCK for teaching the diffusion and osmosis. This study addresses the gap in the literature by examining the PCK and practice of high school biology teachers for teaching the phenomena to high school biology students.

Recognizing common themes and gaps in understanding of the nature of PCK held by experienced teachers and how that knowledge is drawn upon when teaching specific scientific topics provides important insight into teaching and learning. The importance of mentor teachers stimulating reflection of prospective teachers upon their teaching practice was a major theme in science and mathematics education literature. It is important to note that before we can understand how prospective and novice teachers learn to teach we must first understand the nature of PCK held by experienced teachers. How experienced teachers draw upon that knowledge when teaching specific topics in science provides important insight into the integration of knowledge during teaching. By understanding the knowledge and practice of experienced teachers for teaching specific topics in science, teacher educators can unpack teacher knowledge and identify the knowledge of learners, representations, instructional strategies, and assessments

necessary for effective teaching and learning. The knowledge of teacher PCK gained by investigating the nature of PCK among experienced teachers can inform the design and content of teacher professional development. I strongly believe the next logical step in science education research is to investigate the PCK held by experienced teachers for teaching specific topics in science.

CHAPTER THREE: THE RESEARCH PROCESS

Research Questions and Tradition

The purpose of this study was twofold: (a) to investigate the nature of knowledge for teaching concepts related to osmosis and diffusion held by experienced biology teachers serving as mentors for prospective teachers enrolled in an alternative certification program (ACP), and (b) to investigate how the components of topic-specific teacher knowledge are drawn upon by experienced biology teachers when teaching diffusion and osmosis to tenth grade biology students. The Magnusson et al. (1999) model defines teacher knowledge as pedagogical content knowledge which includes orientations to science teaching, as well as knowledge of learners, instructional strategies and representations, assessment, and curriculum. The overarching research question guiding this study was: When teaching lessons on osmosis and diffusion, how do experienced biology teachers draw upon their topic-specific pedagogical content knowledge?

To answer this question, I developed the following sub-questions:

1. What are the nature and sources of experienced biology teachers' orientations to science teaching?
2. What is the nature of experienced biology teachers' knowledge of representations and instructional strategies and how does this knowledge inform their teaching practice?
3. What is the nature of experienced biology teachers' knowledge of students' understanding of science and how does this knowledge of science learners inform their teaching practice?

4. What is the nature of experienced biology teachers' knowledge of formative assessment strategies and how does this knowledge inform their teaching practice?
5. What is the nature of experienced biology teachers' knowledge of biology curriculum and how does this knowledge inform their teaching practice?
6. In what ways do experienced teachers integrate the topic-specific components of their pedagogical content knowledge when teaching osmosis and diffusion?

These questions focus on the nature of knowledge held by experienced biology teachers and my interpretation of how they draw upon and utilize their knowledge within the context of their practice.

Constructivism

Constructivism is an important theoretical paradigm in science education research and involves the construction of individual meanings; thus, teachers observed in the field are constructing teacher knowledge through their interpretation of the events taking place in the classroom (Carlson, 2007). Constructivism holds the view that “all knowledge, and therefore all meaningful reality as such, is contingent upon human practices, being constructed in and out of interaction between human beings and their world” (Crotty, 2003, p.42). Therefore, the constructivist perspective is best suited for investigating how individuals incorporate new knowledge into their existing knowledge and then make sense of this new construct (Ferguson, 2007). Participants in this study are constructing their knowledge of teaching through the prism of their classroom experience and knowledge for teaching biology.

Stake (1995) posits that the majority of contemporary qualitative researchers perceive knowledge as being constructed rather than discovered (p. 99). The constructivist perspective addresses the unique experiences of the individual and investigates how the individual makes sense of his/her experiences to construct an understanding of the world. In terms of qualitative research, the constructivist perspective suggests that knowledge is co-constructed between the study participant and the researcher (Stake, 1995); hence, making meaning out of the life experiences of study participants results in knowledge that is constructed rather than discovered (Crotty, 2003). A constructivist perspective informed the research tradition employed within this study; the knowledge and experiences of each study participant are considered to be unique.

Guba and Lincoln (1989) posit that the constructivist perspective is most appropriate when an inquiry into the human experience is conducted. The assumptions which define the constructivist paradigm are defined by Lincoln and Guba (1985) and include: “the construction of multiple realities which can only be studied holistically; the researcher and participant interact with and influence one another; and knower and known are inseparable” (pp. 37-38). Crotty (1998) reported that constructivist research requires openness to new interpretations and the utilization of interpretivist strategies to construct meaning, and to make sense of data and researcher experiences in the field.

Hatch (2002) posits the naturalistic inquiry is a prototype for constructive qualitative research and notes that the researcher “captures naturally occurring activities in a natural setting” (p. 27). Teachers’ experiences within the context of the classroom and interactions with students will ultimately shape their teacher knowledge. Carlson

(2007) posits each teacher constructs a unique lens through which experiences are interpreted and meaning is constructed.

Teachers integrate the components of their knowledge of teaching to create meaningful learning opportunities for their students. Beliefs about science teaching and learning are constructed from experiences with students and are formulated within the context of the classroom to influence instructional decisions and subsequent actions during teaching (Magnusson et al. 1999). Participants in this study were observed constructing their knowledge of teaching through the prism of their classroom experiences and perspectives of their role as teacher and the role of students as learners. Because knowledge held by each study participant is unique, a constructivist qualitative research tradition and case study methodology informed the design, implementation, and analysis within this study. As the researcher, I assumed a subjectivist epistemology in which I constructed a unique understanding of the data with the participant and an ontological relativity, in that I understand that multiple realities exist within the context of the participants. Because I observed teachers interacting with students within their classrooms and captured teachers' activities within their natural setting, I assumed naturalistic methodological procedures (Denzin & Lincoln, 1985; Hatch, 2002; Patton, 2002).

Epistemological Assumptions

Epistemology is the branch of philosophy that is concerned with how knowledge is developed (Patton, 2002). Within the context of the constructivist paradigm there is an assumption that the meaning of the data will be shaped by the intersection of the perceptions of the researcher and the study participants (Patton, 2002; Merriam et al.

2002). Magolda (2004) posits that individuals actively engage in construction of meaning from their experiences; they interpret, evaluate, and draw conclusions based upon their unique perspective, experiences and assumptions. Hence, teachers construct their knowledge of teaching largely through their experiences in the classroom; their unique perceptions of teaching, learning, and learners influence the nature of their knowledge. There are important implications for data interpretation and analysis in that the experiences and perceptions of the researcher play an important role in constructing the meaning from the data. Patton (2002) posits researchers continually “work back and forth between the evidence and his or her own perspective and understanding to make sense of the evidence” (p. 477).

Hatch (2002) posits that making meaning from the large data set gathered through interviews, observations, field notes, and artifacts is well suited for the inductive model. Inductive analysis begins with complex data taken from a variety of sources and continues as patterns, themes and categories are detected within the data, and findings emerge as the data is analyzed (Patton, 2002). Meaning is made from the data by both the researcher and study participants; because each has a unique interpretation, there is the potential for multiple meanings to be derived from the same data (Patton, 2002). As the researcher, studying the knowledge of teaching held by the participants in this study, I understand that the constructivist tradition assumes that knowledge is individually constructed and ultimately filtered through life experiences and personal beliefs (Denzin & Lincoln, 2005; Hatch, 2002; Patton, 2002). In this study, I focused on the topic-specific pedagogical content knowledge held by experienced biology teachers for teaching diffusion and osmosis. I observed each participant teaching two consecutive

lessons on diffusion and osmosis. Data was collected from multiple sources including: lesson plans, classroom observations, three semi-structured (Patton, 2002) interviews, and lesson artifacts. To clarify my perception and interpretation of teachers' knowledge, instruction, and interactions with students, I asked questions during semi-structured interviews (Patton, 2002).

Ontological Assumptions

Ontology is the branch of philosophy concerned with the beliefs about the status of knowledge. Guba and Lincoln (1989) posited that truth is a matter of consensus among individuals. Within the context of education research, each teacher uses a unique lens to construct meaning (Magnusson, et al. 1999), hence, the nature of teacher knowledge is unique to the individual teacher (Carlson, 2007). The basic ontological assumption of constructivism is that individuals construct their knowledge of reality and this knowledge is independent of a basic foundational reality (Patton, 2002). Each individual constructs his or her knowledge of the world through an interpretation of external stimuli ultimately integrating those interpretations to create an individual perception of the world (Stake, 1995). The constructivist perspective in education research provides a means of gaining insight into the nature of knowledge for teaching possessed by individual teachers. The participants in this study were all experienced tenth grade biology teachers; however, their backgrounds, experiences, and the context in which they taught differed significantly. By maintaining a constructivist perspective, I was able to make sense of each participants' topic-specific knowledge for teaching within the context of their beliefs and experiences. The knowledge held by these participants is unique and cannot be generalized to other teachers.


Context of the Study

The study was conducted within partner high schools associated with an alternative certification program (ACP), the “Alternative Science Teacher Education Program” (ASTEP) . Experienced teachers selected to participate in this study were teaching at partner schools and selected to serve as mentor teachers for interns enrolled in the ASTEP alternative certification program.

Overview of ASTEP

Because ASTEP has been designed to meet the needs of a wide range of students, it offers two distinct tracks: the Accelerated Post Baccalaureate program (APB) and the Alternative Certification program (ALT). The timeline for APB prospective teachers is shown in Table 2.

Table 2. *Timeline of APB teacher certification program*

<i>Summer-Year 1</i>	<i>Fall-Year 1</i>	<i>Winter-Year 1</i>	<i>Summer-Year 2</i>
Advanced Educational Foundations of Teacher Preparation (8 credits)	Teaching, Learning, and Research in Secondary School Science II (3 credits)	Teaching, Learning, and Research in Secondary School Science III (3 credits)	Integrating Mathematics and Science Instruction (2 credits)
Teaching, Learning, and Research in Secondary School Science I (3 credits)	Reading in the Content Areas (2 credits)		Complete Portfolio and Action Research
	 Mentored Internship completed during the fall and spring semesters (20 hours per week) (8credits)		

Interns in the APB track are full-time students, they enter the program during the summer and complete intensive coursework designed to prepare them for a 32-week mentored internship at a partner school. APB interns earning middle school or secondary certification spend 32 weeks completing a mentored internship at either a middle school or high school. APB interns opting for dual certification in both middle school and high school science teaching spend the first 10-weeks at a middle school working with a

middle school mentor teacher and the remaining 22-weeks at a high school working with a high school mentor teacher. Interns continue taking methods classes throughout both semesters of the internship.

Selection of mentor teachers. The selection of mentors is informed initially by recommendations from school principals. Feedback regarding mentor effectiveness is derived from two sources including: a survey on mentor effectiveness completed by interns and observations of mentor teachers made by the university supervisor for the ASTEP alternative certification program. This feedback provides key indicators for the selection and/or retention of mentor teachers.

ASTEP Research Project

This study was conducted within the context of a larger, NSF funded study entitled: Alternative Science Teacher Education Program Research Project (ASTEP-RP). ASTEP-RP examines science and mathematics teacher learning within the context of an ACP (i.e., ASTEP).

ASTEP-RP is a longitudinal study and follows intern participants enrolled in the APB track over a two year period beginning the summer they enter the program, continuing during their one-year mentored internship, and ending with the completion of their first year of full-time teaching. The participants in my study were selected from the experienced biology teachers serving as mentor teachers during the 32-week mentored internship completed by APB interns.

ASTEP-RP research has four major goals: (1) to advance the knowledge base related to teacher preparation within the context of an ACP; (2) to advance the knowledge base regarding teacher learning within the context of a clinical field experience; (3) to

understand the factors that facilitate and constrain teacher learning; and (4) to prepare a new generation of researchers in teacher knowledge research. Thus, ASTEP-RP researchers are engaged in an investigation into teacher learning taking place within two distinct tracks (APB and ALT) within an ACP.

As a longitudinal study, ASTEP-RP involves data gathering from 5 cohorts of science teachers at 7 checkpoints during the mentored ACP internship and throughout the first year of full-time teaching. The data gathering points include lesson plans gathered during entry and exit tasks as well as during each of the observation cycles during Year 1 and 2 of the study. A full description of all data collection points is shown in Table 3.

Table 3. *ASTEP-RP data collection points*

Data Collection Checkpoint	Lesson Plan	Interviews	Written Reflection
Entry Task	Planning for 2 consecutive days of instruction	Entry task interview about entry task planning	
End of Summer		End of Summer Interview	
Fall Observation Cycle-Year 1	Planning for two days of actual instruction	Pre-Observation Simulated Recall-1 Simulated Recall-2 Mentor teacher interview	Response to reflective prompts about lesson
Winter Observation Cycle-Year 1	Planning for two days of actual instruction	Pre-Observation Simulated Recall-1 Simulated Recall-2 Mentor teacher interview	Response to reflective prompts about lesson
Fall Observation Cycle-Year 2	Planning for two days of actual instruction	Pre-Observation Simulated Recall-1 Simulated Recall-2	Response to reflective prompts about lesson
Winter Observation Cycle-Year 2	Planning for two days of actual instruction	Pre-Observation Simulated Recall-1 Simulated Recall-2	Response to reflective prompts about lesson
Exit Lesson Planning Task	Planning for two days of lessons – exit task prompts are identical to entry task	Exit task interview about exit task planning	

My study implemented observation and interview protocols very similar to the protocols used within the ASTEP-RP study. Teachers participating in my study submitted two consecutive lesson plans for teaching the concepts diffusion and osmosis to tenth grade biology students. A pre-observation interview provided insight into teacher subject matter knowledge, topic-specific PCK, and lesson planning. Next, the teachers were

observed and videotaped teaching the lessons. As the researcher, I identified specific occurrences within the lessons to stimulate participant recall and discussion during stimulated recall interviews following each observation. Participants were asked questions designed to probe deeper into their knowledge of the components of Magnussen et al.'s (1999) PCK model (e.g., orientation to science teaching, knowledge of representations, instructional strategies, students, assessment, curriculum). The interview protocols for my study are found in Appendix A.

My Role in ASTEP-RP

I served as a graduate research assistant (GRA) with the ASTEP-RP team from the September of 2006 through September of 2009. Throughout my assistantship I participated in all aspects of research design, data collection, development of analysis tools, and initial data analysis. I have coded a significant portion of the data and contributed to two conference presentations and two journal manuscripts generated by the project.

Because of my extensive experience as a high school biology teacher, I am very interested in the topic-specific knowledge of teaching held by experienced high school biology teachers. While working as a GRA with ASTEP-RP, I began to wonder how lessons would be different if taught by an experienced teacher. By placing all of the emphasis on pre-service teachers and novice teachers, a picture of teacher knowledge possessed by experienced teachers was not developed within the study. An understanding of the knowledge of teaching and the practice of experienced teachers would provide important insights into teacher preparation and qualifications critical to success in twenty-first century science education (Zeichner, 2005). Therefore, I chose to investigate

the knowledge of teaching held by experienced biology teachers selected to serve as mentors for the ASTEP program and how they draw upon that knowledge when teaching concepts directly related to osmosis and diffusion to a tenth grade biology class.

Study Participants

The participants in this study were six experienced high school biology teachers serving as full time mentor teachers in partner schools for the ASTEP program.

Participants will be referred to by pseudonyms Emma, Janis, Kasey, Jason, Lana, and Cathy. Personal participant data can be found in Table 4.

Table 4. *Participants' Personal Data*

Personal Data			
Pseudonym	Teaching Experience	Gender	Ethnicity
Janis	15	Female	White (Non-Hispanic)
Emma	8	Female	White (Non-Hispanic)
Jason	15	Male	White (Non-Hispanic)
Kay	7	Female	White (Non-Hispanic)
Cathy	15	Female	White (Non-Hispanic)
Lana	19	Female	White (Non-Hispanic)

Purposeful Sampling

Several criteria guided my selection of study participants. I purposefully selected all six participants from secondary science teachers serving as mentor teachers for ASTEP interns. Schulman (1986) noted that PCK is a form of teacher knowledge which draws heavily upon individual's knowledge of content, hence researcher knowledge of content is important. Because of my extensive experience as a secondary biology teacher, I selected only secondary biology teachers based upon my experience as a biology teacher and as a researcher.

My goal was to identify experienced teachers who were highly thought of by their building principals. Selection to serve as a mentor teacher for ASTEP interns is predicated initially upon recommendation by the building principal. This is an important

indication that teachers are highly regarded by building administrators and likely to possess the knowledge and expertise to mentor interns. Berliner (2001) identified nomination by school administration to serve as a mentor for interns as a criterion for identifying expert teachers. Teaching experience is also an important factor; I only selected biology teachers with a minimum of five years of teaching experience. Participants' teaching experience ranged from a minimum of seven years to a maximum of nineteen years. All participants are certified biology teachers and were currently teaching tenth grade high school biology. Four of the teachers, Cathy, Janis, Emma, and Lana participate in the Partnership for Research and Education in Plants (PREP) professional development program which I coordinate through the University Science Outreach Office. Through this program mutant and wild-type *Arabidopsis* seeds provided by plant research scientists, serve as the foci for student driven research. Students investigate seed germination and plant growth among wild-type and mutant seeds to find clues to the function of uncharacterized *Arabidopsis* genes. Hence, I was aware of that these teachers were highly regarded teachers who held strong knowledge of subject matter as well as well developed PCK.

Participant Schools/Districts

The six teacher participants are full time high school biology teachers in high schools within six different school districts located within a mid-western state. All district and high school names are pseudonyms. Demographic information about each community in which the partner school districts are located is shown in Table 5.

Table 5⁵: *Comparison of Societal Factors between Participant’s School Districts*

Participant	School District	Community Societal Factors – 2000 Census Information	
		Population Served	Average Household Income
Janis	Bannister	66,059	\$68,601.00
Emma	Bing	10,931	\$42,136.00
Jason	Carlville	6,849	\$45,489.00
Cathy	Fender	17,827	\$44,374.00
Lana	Miller	15,615	\$42,805.00
Kay	Rollins	112,803	\$49,576.00

All demographic information has been retrieved from the Department of Elementary and Secondary Education (DESE) website. The communities served by the school districts have populations ranging between 6,849 and 70,000 (2000 U.S. Census). The most affluent population with an average household income of \$68,601.00 is found in the Bannister school district. The average household incomes of the remaining communities are similar, ranging from \$42,136.00 to \$49,576.00 (2000 U.S. Census).

There is greater variation found within the demographic information for the high schools related to student enrollment and graduation rates. All demographic information related to students and schools was taken from the DESE website. An overview of the enrollment, graduation rate, eligibility for reduced/free lunch, and the student to staff ration is shown in Table 6.

Table 6⁶. *Contextual Factors in Participants’ School*

	Contextual Factors			
	High School Demographic Information			
High School	Enrollment	Graduation Rate (%)	Free/Reduced Lunch (FRL) (%)	Student to Staff Ratio
Bannister	1,430	94.4	9.50	23/1
Bing	617	92.1	40.50	18/1
Carlville	395	85.6	24.40	18/1
Fender	762	79.7	28.30	19/1
Miller	769	82.2	35.30	20/1
Rollins	1,716	92.0	12.10	23/1
State	894,609	85.2	42.1	18/1

^{5,6}Note: From “*School Data and Statistics*,” 2000 Census demographics, Department of Elementary and Secondary Education, <http://dese.mo.gov/planning/profile/048068.html>

The staff to student ratios range from 18 students per teacher to 23 students per teacher for all schools included in the study. The highest graduation rate is held by Bannister High School; the affluence of this community is reflected in the low percentage of students eligible for free/reduced lunch. Interestingly, the second highest student graduation rates are held by Bing and Rollins High Schools. These schools differ markedly in terms of the total enrollment and the average household income. Patron families for Bing High School earn an average income approximately \$7,000.00 less than that of patron families for Rollins High School. Thus, a major difference between Bing and Rollins schools is the percentage of students eligible for free/reduced lunch. Bing High School has the greatest percentage of students eligible for free/reduced lunch.

The level of ethnic diversity differed among partner schools (see Table 6). Carlville High School had the least ethnic diversity among participants' schools with only 1.5% of the student body identified as minority students. Bannister and Rollins High Schools had the greatest percentage of minority students at 18.8% and 19% respectively. Variations in ethnic diversity among the schools are shown in Table 7.

Table 7⁷. *Comparison of Ethnic Diversity*

Comparison of Ethnic Diversity					
School Demographic Information					
High School	White (%)	Black (%)	Hispanic (%)	Asian (%)	Indian (%)
Bannister	81.20	12.20	3.60	2.40	0.60
Bing	84.30	11.70	1.90	2.00	0.10
Carlville	98.50	1.00	0.00	0.30	0.30
Fender	87.90	11.00	0.70	0.30	0.10
Miller	86.60	10.50	2.20	0.40	0.30
Rollins	81.10	11.90	2.10	4.50	0.50
State	76.2	18.0	3.6	1.8	0.4

⁷Note: From "School Data and Statistics," 2000 Census demographics, Department of Elementary and Secondary Education, <http://dese.mo.gov/planning/profile/048068.html>

An analysis of the graduating seniors at each of the participants' school districts indicates varying career paths among the school districts' students. The analysis indicates the majority of graduating students in each district attend a four-year college/university. However, there is a notable difference in the percentage of students within each district electing to attend a four year college/university. Carlville and Miller were the only districts to fall below the state average for the percentage of students electing to attend a four-year college/university (see Table 8). The percentage of students from Bannister, Bing, Fender, and Rollins High Schools electing to attend a four-year college or university ranged from a high of 62.6% to a low of 44.3%.

Table 8⁸. *Analysis of Graduates in Participants' School Districts*

Analysis of Graduating Seniors							
High School	4 year College University	2 year College	Post Secondary Noncollege Institution	Work Force	Military	Some other field	Status unknown
Bannister	62.60	19.00	0.20	12.80	4.00	1.50	0.00
Bing	44.30	27.0	1.60	20.50	2.50	4.10	0.00
Carlville	35.30	21.20	2.40	31.80	7.10	0.00	2.40
Fender	45.60	16.30	3.80	28.10	1.90	3.80	0.60
Miller	38.70	14.90	8.30	24.40	3.00	4.20	6.50
Rollins	55.50	19.50	2.00	21.70	1.10	0.10	0.10
State	39.9	26.8	3.5	18.9	3.1	2.4	5.5

The schools in which participants taught ranged from rural to suburban with significant differences within the affluence of patron families, minority enrollment, graduation rates, and college attendance. However, a common thread for all schools lies within the district and state (e.g., End of Course Exam) guidelines from which the biology curriculum is formulated.

⁸Note: From "School Data and Statistics," 2000 Census demographics, Department of Elementary and Secondary Education, <http://dese.mo.gov/planning/profile/048068.html>

Design of the Study

Case Study Approach

Case studies are detailed investigations of individuals, groups, or institutions within their own unique context (Patton, 2002). Yin (2003) described the case study through the lens of the research process as “an empirical inquiry that investigates a contemporary phenomenon within its real-life context when the boundaries between phenomenon and context are not clearly evident” (p. 13). Stake (1995) described a case study as the study of the unique nature and complexity of a single unit or entity (e.g., a child, a teacher, a school) in which the researcher comes to understand the experiences of that entity within a specific context. Merriam (1998) defined the case study as an “intensive, holistic description and analysis of a single instance, phenomenon, or social unit” (p. 27). Creswell (1998) perceived the case study as an exploration of a “bounded system” over time and involving detailed and in-depth data collection from multiple sources (e.g., interviews, documents, observations, field notes, etc.). A bounded system constitutes an assemblage of interacting factors or parts which form a functioning whole (Stake, 1995). Thus, the nature of the case study is to conduct an in-depth investigation of the unit of study (individual, group, or institution) within the context or environment unique to that unit of study. This research presents an in-depth perspective of the knowledge for teaching held by experienced biology teachers and how the teachers draw upon that knowledge when teaching content directly related to osmosis and diffusion.

A bounded system describes specific parameters for the study (Creswell, 1998). Smith (1978) introduced the concept of the case as a bounded system; he noted there

must be specific limitations on the scope of the case. Thus, a case must have boundaries, therefore, a teacher, a child, or a school could be identified as a case; however, when the focus of study becomes too broad or lacks boundaries, the distinction of a case study no longer applies. Merriam (1998) described the case as a single entity to be studied around which there exist boundaries enabling the researcher to focus his or her research. A bounded system identifies limitations; in this study, research was focused on topic-specific teacher knowledge drawn upon by six experienced 10th grade biology teachers when teaching two consecutive lessons on osmosis and diffusion.

Case studies can be designed as single or multiple cases. Thus, a study may contain more than a single case and when this occurs, the study is noted to be a multiple case study (Yin, 2003). This study is focused on six participants; each participant constitutes an individual case; hence, this study constitutes a multiple-case design (Yin, 2003). Merriam (1998) noted the inclusion of multiple cases within a case study is a means by which the external validity or generalizability of study findings can be enhanced (p. 40).

The case study approach was selected because it was the best fit for data collection and analysis for this study for several reasons. First, the case study has a distinctive advantage over other research designs because “the strategy employed is to investigate ‘how’ or ‘why’ questions asked about a contemporary set of events over which the researcher has no control” (Yin, 2003, p. 9). Second, a case study design is also favored when there are multiple forms of data (Merriam, 1998; Yin, 2003). Yin (2003) and Patton (2002) identify the reliance upon multiple sources of evidence as a unique strength of the case study research approach. Multiple forms of data were collected for this study

including observations in the field during which teacher participants were observed and videotaped teaching specific content related to the topic of osmosis and diffusion. Data collection protocols were designed to provide a holistic view of teacher knowledge. Thus, primary data collection protocols consisted of field observations and semi-structured interviews (Patton, 2002) conducted prior to and following field observations. Secondary data sources consisted of teacher materials including lesson plans and other lesson materials and artifacts. All data was gathered within a real-life context as teacher participants were observed teaching the same content specifically related to tenth grade biology Course Level Expectation (CLE) for osmosis and diffusion. Third, the case study has the potential to provide specific insight into how individuals confront and solve problems. The case study is described by Merriam (1998) as “being particularistic, descriptive, and heuristic” (p. 29), indicating the case study is focused on a specific event and has the potential to provide significant insight into how individuals confront problems through a holistic view of the situation.

Each of the six mentor teacher participants constitutes a unique case influenced by their past experiences, their perspectives of teaching, learning, and learners, and the context in which they are teaching. My goal was to understand the nature of topic-specific pedagogical content knowledge (PCK) draw upon by experienced high school biology teachers when teaching osmosis and diffusion to tenth grade biology students. Teacher knowledge was conceptualized by Magnusson et al. (1999) as pedagogical content knowledge (PCK) and included the following: (1) the orientation to science teaching held by the participant; (2) knowledge of instructional strategies and representations; (3) knowledge of potential student difficulties with content;

(4) knowledge of assessment strategies; and (5) knowledge of curriculum and curricular resources. Yin (2003) explains that a single case design and a multiple cases design are considered to be variants within the same methodological framework. Because of the six participants included in the study, Yin (2003) would likely identify this study as a multiple case design.

Methodological assumptions. One of the most important assumptions associated with this research is that the actions of the participants cannot be controlled in any way by the researcher. The researcher functions only in the role of an observer and is, therefore, unable to affect the actions of study participants. The value of a case study methodology is that the researcher is able to observe participants within the context of the classroom and school while utilizing multiple data sources to understand their knowledge and practice for teaching osmosis and diffusion. Stake (1995) posits that as a researcher, one is an interpreter placed in the field to observe the “workings of a case” (p. 8).

Limitations of case study research. As a researcher it is critical for me to identify the limitations of this study and acknowledge the limitations of the research strategy. Limitations are factors that have the potential to constrain the study and are generally out of the control of the researcher. The researcher must decide how much data is necessary to answer study questions within the timeline of the study.

In this study, I chose to observe six teacher participants for two consecutive lessons focused on osmosis and diffusion. My goal was to gain an understanding of the nature of the topic-specific pedagogical content knowledge held by experienced biology teachers. My research protocol consisted of a single observation cycle of two lessons beginning with a pre-observation interview after the submission of lesson plans followed

by two stimulated recall interviews following the observation of each lesson. The protocol was designed to capture teacher topic-specific pedagogical content knowledge. The first limitation noted is that only two lessons were observed rather than the entire unit. I made the decision to follow the observation protocol of the ASTEP-RP research study to allow for future studies in which comparisons between the pedagogical content knowledge of ASTEP interns and experience mentor teachers could be made.

The second limitation of the study is related to the selection of teacher participants. Participant selection was limited to experienced tenth grade biology teachers selected to serve as mentors for interns enrolled in ASTEP Program. There may have been other experienced teachers who might contribute a great deal to the study but did not fit the selection criterion. The sampling strategy implemented in this study was designed to fit the purpose of the study (Patton, 2002) which was to investigate the nature of topic-specific pedagogical content knowledge held by experienced biology teachers. Therefore, teachers selected for the study were highly thought of and recommended to serve as mentors by the building principal, taught for a minimum of five years, were certified to teach biology at the high school level, and also were teaching tenth grade high school biology at the time of the study.

The third limitation references documents, materials, and artifacts gathered during the study (e.g., lesson plans, PowerPoints, student handouts, etc.) Documents collected during the study can be a limiting factor because such documents may be incomplete (Patton, 2002) and only reflect limited aspects of teacher knowledge. Therefore, multiple data sources were utilized for this study including direct observation, semi-structured interviews (Patton, 2002) prior to and following field observations, researcher field notes,

and lesson artifacts (lesson plans, student handouts, and other artifacts). Patton (2002) notes that taken together diverse data sources provide a more complete picture of study participants.

Role of the Researcher

My role as researcher was influenced by my experience as a high school biology teacher. I entered graduate school after a twenty-three year career as a secondary biology teacher. My experience in secondary education was truly exceptional; I earned National Board Certification in Adolescent and Young Adult Science in 1998 and won the Presidential Award for Excellence in Science Teaching in 2000. As a graduate student, I initially served as a university supervisor for interns in an Alternate Certification Program (ACP) for secondary science teachers. After two years of intern supervision, I became a graduate research assistant (GRA) and examined the development of PCK among interns within an ACP. My role consisted of observing and videotaping ACP interns teaching lessons as well as conducting interviews with interns prior to and following observations of each lesson of the research observation cycle. Hence, as a GRA, I gained insight into the development of teacher knowledge among prospective teachers. As I observed interns teaching topics in biology, I reflected upon my own experiences as a secondary biology teacher and wondered how the lessons would look if taught by an experienced teacher.

As a secondary biology teacher, my overarching goal in teaching biology was to stimulate students' interest in biology, make concepts relevant, and encourage students to think critically. In my practice as a teacher, I consistently designed lessons to engage students with hands-on and minds-on exploration of concepts. I believed students learned most effectively when engaged as active participants in learning. Conceptual

understanding of diffusion, osmosis, and the nature and function of cellular membranes are critical to understanding other concepts in biology (e.g., photosynthesis, water movement in plants, and cellular respiration). When teaching diffusion and osmosis, I initially engaged students with food dye and water as representations of diffusion. I used water at temperature extremes (e.g., water heated to nearly 100°C and water chilled to nearly 0°C) to emphasize kinetic energy and molecular motion in diffusion. I challenged students to predict changes within the food coloring within each temperature and test their predictions by observing changes in drops of food dye placed in water at each temperature. When asked to explain their observations, students noted the temperature of the water as the only difference between the representations of diffusion. I encouraged students to reflect upon their knowledge of matter and energy addressed in ninth grade physical science. Hence, my goal was to support students' understanding of molecular motion as the driving force for diffusion. When investigating osmosis, I used dialysis tubing and decalcified eggs as representations of cells and the foci for student explorations of osmosis. Students' reflected upon their observations of changes within the dialysis tubing or decalcified egg to explain the direction of osmosis. I required students to support claims with evidence (e.g., mass of dialysis tubing and decalcified egg and the color of the starch solution within the tubing) and encouraged students to reflect upon their observations of diffusion when developing explanations for the net direction of water movement during osmosis. My experience indicated the focus on molecular motion as the driving force for diffusion helped students understand osmosis as the diffusion of water also driven by random molecular motion.

I had two reasons for selecting diffusion and osmosis as lesson topics. First, the concepts require students to integrate knowledge of cell membrane structure and function, relative solute and solvent concentrations, the particulate and random nature of matter, and dynamic equilibrium (Odom & Barrow, 1995; Tekkaya, 2003). As a result, diffusion and osmosis are challenging concepts for both students and teachers. Second, diffusion and osmosis are among Missouri Course Level Expectations and included within the End of Course Exam for tenth grade biology. Hence, the concepts are part of the curriculum in all tenth grade biology courses.

During my career as a high school biology teacher I taught with one of the teachers participating in my study. I acknowledge that my knowledge of this individual prior to the onset of my research could be a potential source of bias. When interviewing teacher participants, I relied upon experience gained as a graduate research assistant with data collection procedures and interview protocols of ASTEP-RP research to remain focused on the questions guiding the study. I was never a participant in any of the lessons observed and did not interact with students or the teacher in any way until I conducted the interviews at a prearranged time prior to and following lesson observations.

Institutional Review Board

This study was conducted through the larger NSF funded ASTEP-RP study in that my focus was on the mentor teachers in the study. Therefore, I submitted an amendment to the ASTEP-RP for approval by the Institutional Review Board (IRB) to gain permission to conduct research with the mentor teachers engaged within the ASTEP-RP project to investigate their pedagogical content knowledge for teaching specific biology content related to osmosis and diffusion. IRB approval was granted on August 14, 2008.

Letters explaining my research, participant involvement, and the videotaping of participant teachers' classrooms were sent to building principals. Following letters to the principals, I contacted each principal by phone to explain my research and answer questions and respond to concerns. Written consent was received from the principals of all schools participating in the study. Permission to videotape Janis while teaching at Bannister High School was denied, therefore, Janis was observed teaching two lessons but not videotaped.

Written consent to participate in my research was obtained from all teacher participants. Because teacher participants were videotaped teaching lessons within their classrooms, parents of students in participants' classrooms were informed of the videotaping and their written consent was also requested. Students whose parents requested that they not be taped or those who did not return the consent forms were located within the classroom where they would not be captured on video. During videotaping, I was very careful to focus on the teacher participant and interactions between the teacher and those students who had parental permission to be videotaped. The consent forms for my study are found in Appendices B, C, and D.

All consent forms, audiotapes, and video cassettes generated during my data collection will be stored in a locked file cabinet for a minimum of three years following the completion of data collection.

Data Collection

Data collection was taken from multiple sources and included videotaped field observations of two consecutive days of teaching, researcher field notes, three audio-recorded, semi-structured interviews (Patton, 2002), and the collection of lesson artifacts

(e.g., lesson plans, hand-outs, PowerPoints, worksheets, etc.) from teacher participants. One of the strengths of the case study design is that many sources of evidence can contribute to the data for case studies (Merriam, 1998; Yin 2003). Patton (2002) notes data gathered from multiple sources is a form of triangulation; one can compare the “consistency of findings generated from different data sources within the same method” (p. 556). Yin (1994) describes the use of multiple sources of evidence as a strength of the case study because multiple sources of evidence allow for triangulation of the data sources. Sources of evidence used in this study included: observations, semi-structured interviews (Patton, 2002), researcher notes, videotapes, lesson plans, and lesson artifacts. I compared observations of the participants with their explanations during interviews to gain insight into their knowledge and beliefs about teaching and learning. The data collection protocol for study participants in this study follows the protocol similar to that developed by the ASTEP-RP team. A description of the data collection protocol follows.

Lesson plans. Lesson plans for two days of consecutive days of instruction focused on the topic of osmosis and diffusion and were submitted by each participant prior to the field observations. All participants were observed teaching the same lesson topic to provide a more accurate basis for cross-case comparisons (Yin, 2003). Within the context of the lesson plan, study participants were asked to describe their plans for the beginning, middle, and end of each lesson. All teacher artifacts, including handouts, worksheets, PowerPoint notes, laboratory investigations, etc. were collected from teacher participants as part of their lesson plans. The lesson plan request can be found in Appendix E.

Pre-observation interview. Following the submission of lesson plans and prior to the field observation, a pre-observation, semi-structured interview (Patton, 2002) was conducted. The purpose of the pre-observation interview was to explore the nature of teacher knowledge held by the teacher concerning learners, curriculum, instruction, and assessment strategies related to the topic of osmosis and diffusion, as well as, the participants' orientation to science teaching. The interview was conducted within the high school of each participant prior to the observation and took between 60 to 80 minutes. During the pre-observation interview, participants were asked to reflect upon their planning and explain their decisions to include specific strategies, representations, assessments, etc. in the lessons. Minor modifications were made to the pre-observation interview protocol to reveal the pedagogical content knowledge of experienced teacher participants. I transcribed all of the interviews in preparation for coding. The pre-observation interview can be found in Appendix A.

Field observations. Following the pre-observation interview, the participants were observed and videotaped teaching their lesson plans. During the observation, I made researcher field notes to describe instruction, make theoretical memos, and note occurrences of interest which took place during the lesson. Interesting occurrences were played back for participants during the stimulated recall interviews to stimulate participant reflection and subsequent explanations about his/her teaching. Field notes were utilized as an important tool to further delineate the manner in which the participants articulated their knowledge of learners, curriculum, instruction and assessment.

Stimulated recall interview. Each lesson observation was followed with a stimulated recall interview (See Appendix A). The interviews were conducted in the high schools of each of the participants; interviews took between 60 and 80 minutes. The participants were asked to reflect upon the lesson and explain: (a) their concerns for student comprehension of content, (b) their choice of instructional strategies and representations, and (c) their use of formative assessment strategies to gauge students' learning. Participants were also asked how they modified their instruction to address student learning difficulties during the lesson. Each lesson was videotaped to provide a record of the lesson for future reference and specifically to stimulate participant reflection during the stimulated recall interview. A data collection matrix identifying the data sources for each research sub-question is shown in Table 9.

Table 9. *Data Collection Matrix*

Research Questions	Data Sources	Interview Questions
1. What are the nature and sources of experienced biology teachers' orientation to science teaching?	Lesson plans submitted by teacher	
	Pre-observation interview	#1b, 1c, 1d, 1e
	Stimulated-recall interviews	#22a, 22b, 22a, 22b, 22c, 22d, 22e, 22f
2. What is the nature of experienced biology teachers' knowledge of representations and instructional strategies and how does this knowledge inform their teaching practice?	Student handouts,	
	Pre-observation interview	#11, 12a, 12b, 12c, 12e, 13,
	Stimulated-recall interviews	Videotape, #20
3. What is the nature of experienced biology teachers' knowledge of students' understanding of science and how does this knowledge of science learners inform their teaching practice?	Lesson plans submitted by teacher	
	Pre-observation interview	#6a-e, 7, 8a, 8b, 9
	Stimulated-recall interviews	Videotape, #18, 19, 20
4. What is the nature of experienced biology teachers' knowledge of formative assessment strategies and how does this knowledge inform their teaching practice?	Lesson plans submitted by teacher	
	Pre-observation interview	#16a, 16b, 16c, 16d, 16d, 17a, 17b
	Stimulated-recall interviews	Videotape, #18, 19, 20

5. What is the nature of experienced biology teachers' knowledge of biology curriculum and how does this knowledge inform their teaching practice?	Lesson plans submitted by teacher	
	Pre-observation interview	#14a, 15a, 15b, 15c, 15d,
	Stimulated-recall interviews	Videotape, #18, 19, 20
6. In what ways do experienced teachers integrate the topic-specific components of their pedagogical content knowledge when teaching osmosis and diffusion?	Pre-observation interview	#1f, 1g, 2, 11,
	Stimulated-recall interviews	Videotape, #18, 19, 20

Data Analysis

Data analysis began with the transcription of the interviews immediately following the observation cycle for each participant. I personally transcribed all interviews to gain greater understanding of the participants and the data. All transcribed interviews were carefully reviewed for accuracy. Videotapes were viewed to make sure that important aspects of participants' practice was not missed.

Development of Codes

When developing codes for teacher orientation to science teaching, I drew upon the work of Brown (2008) and Brown et al. (2008) and developed codes within five dimensions of teacher orientation to science teaching including: (1) goals and purposes, (2) perception of teacher role, (3) perception of students' role, (4) ideal images of teaching science, and (5) perception of science as a discipline. I used the Magnusson et al. (1999) PCK model and drew upon codes from the ASTEP-RP study to develop codes for data analysis within the following dimensions of teacher knowledge including: (1) knowledge of representations and instructional strategies, (2) knowledge of students' understanding of science, (3) knowledge of assessment, and (4) knowledge of curriculum. Coding was both deductive and inductive. Codes developed from the five dimensions of teacher orientation (Brown, 2008; Brown et al. 2008) and the four components of the Magnusson et al. (1999) were deductive codes. Inductive codes emerged from the

categories as the transcripts were analyzed. An example of an inductive code would be codes for topic-specific representations used by the teacher for teaching diffusion and osmosis (e.g., the teacher uses a decalcified egg as a representation of a living cell). I used the codes to analyze the data gathered during the study.

Case Profiles

The creation of the case profiles was a multiple step process. First, I combined the data from multiple sources gathered during my research. Second, I analyzed the data using the codes described in the previous section. From the coded data, I constructed a case profile for each participant beginning with their orientation to science teaching within the context of the five dimensions identified by Brown (2008) and Brown et al. (2008) and continuing with an analysis of the components of teacher knowledge identified by the Magnusson et al. (1999) PCK model. I used verbatim data excerpts to tell the story of each participant and to support my interpretation of the teacher's orientation to science teaching and their topic-specific PCK for teaching diffusion and osmosis. I developed a vignette for each participant, situated as an introduction to the case profile, to characterize participants' teaching and introduce the participant to the reader.

I continually referenced the data to find additional evidence; hence, I continually referenced the data throughout the construction of the case profiles to test claims and find supporting evidence. This within-case analysis allowed me to develop specific assertions about each participant in terms of their orientation to science teaching and topic-specific knowledge of teaching osmosis and diffusion (Stake, 1995; Yin, 1994).

Each of the case profiles concluded with a Content Representation (CoRe) (Loughran, Mulhall, & Berry, 2004). The CoRe (Loughran et al. 2004) identifies the important scientific concepts to be taught within the lesson and unpacks the learning goals for students for the lessons as well as teacher knowledge for teaching these concepts to reveal representations, instructional strategies and assessments used during the lessons. My goal in creating a CoRe for each participant was to portray how the teacher conceptualizes lesson content and the topic-specific nature of PCK held by each teacher for teaching diffusion and osmosis (Loughran, Berry, & Mulhall, 2006; Loughran, Mulhall, & Berry, 2004). Hence, the creation of the CoRe enhanced my understanding of the data.

Cross-case Comparison

A cross-case comparison of participants was conducted to make comparisons between the individual case profiles. Patton (2002) posits “understanding unique cases can be deepened by comparative analysis” (p. 56). The process of comparing the orientations and topic-specific PCK across the case profiles allowed me to gain a deeper understanding of the data. Yin (1994) posits that multiple case studies provide the researcher with greater opportunities to explore patterns and themes within the data. I used a cross-case comparison to identify similarities and differences within the orientation and topic-specific PCK of the participants in this study.

Trustworthiness

Trustworthiness is a critical aspect of any research. There must be confidence in the validity and transferability of study results (Merriam, 1998). The ethical considerations of the researcher are critical to ensuring credibility, confirmability, and

transferability in qualitative studies (Merriam, 1998). Credibility, transferability, dependability, and confirmability are the naturalistic criteria for trustworthiness (Lincoln & Guba, 1985, p. 219).

Patton (2003) reports that the credibility of a qualitative study is based upon three distinct elements: (1) rigorous methods to yield high quality fieldwork, (2) the credibility of the researcher which results from the level of training and experience held by the researcher, and (3) the belief in the value of qualitative inquiry held by the researcher. I took several steps to increase the credibility of my findings during data analysis including: triangulation, and peer debriefing.

Triangulation

As a qualitative researcher, it is my responsibility to ensure that credibility of the research is maintained for the naturalistic methods employed during data gathering and data analysis within this qualitative study (Merriam, 1998; Patton, 2002). Because each researcher brings his/her unique views and interpretations into their research, observations and interpretations made by the researcher must be checked by triangulation (reliance upon multiple data sources), member checks, and collaboration with others (Merriam, 1998). I worked to attain confirmability in my research by referring back to multiple data sources to check and recheck the data to find support for my interpretations. The earlier stages of my fieldwork were generative while the later stages of my work involved analyzing the data to develop deeper insights to identify and confirm patterns. First, I gathered data from multiple sources including field observations, field notes, semi-structured interviews, and teacher artifacts. Thus, the consistency of data sources can be checked through a comparative analysis (Patton, 2002) as case profiles are

developed. Second, during data analysis I triangulated from data gathered from multiple sources during the study to identify patterns and construct explanations (Yin, 1994).

Member Checking

I implemented member checking to establish credibility (Lincoln & Guba, 1985). Completed case profiles were sent to all participants for their feedback. The feedback I received was very positive. However, there were requests for minor changes within the profiles. Jason noted he coached track instead of wrestling. Cathy explained the dialysis tubing contained a glucose and starch solution; hence, initially, glucose was placed within the dialysis tubing rather than within the beaker solution of distilled water and iodine. Janis explained she emphasized the nature and structure of the cell membrane along with osmosis during the *Elodea* investigation conducted on Day 1 of the observation cycle. Lana reminded me she intended to have students conduct an inquiry-based investigation during the week following the research observation cycle. She explained that her students would create their own experimental designs for the investigation. Emma and Kacy approved of their case profiles as written. Upon receiving feedback from the participants, I implemented their corrections to more accurately reflect the orientation to science teaching and the topic-specific PCK held by each participant.

Peer Debriefing

Lincoln and Guba (1985) identify four purposes for peer debriefing including: (1) to align the research and researcher with the research questions, (2) to test working hypotheses, (3) to develop and test the next steps in the emerging methodological design, and (4) to provide the researcher with an opportunity for catharsis. I shared my findings with two of my colleagues to access their ideas and views concerning my research.

Feedback from peers enabled me to revisit the data and review my assertions and consider my bias when analyzing the data. I also met with my dissertation advisor weekly to discuss my research and share my findings, assertions, and writing.

CHAPTER FOUR: CASE PROFILES

In Chapter Four, I provide case profiles for each of the study participants. The purpose of the cases is to provide an in-depth profile of study participants' topic specific pedagogical content knowledge (PCK) for osmosis and diffusion and their integration of the components of Magnusson et al. (1999) PCK model.

Each of the case profiles is organized in a manner reflective of the Magnusson et al. (1999) PCK model of teacher knowledge. The case profiles presented here are based upon multiple data sources including observations of participants teaching lessons on osmosis and diffusion, semi-structured interviews (Patton, 2002) conducted prior to and following observations, researcher field notes, and teacher lesson plans and other classroom artifacts associated with the lessons. The cases are based upon my interpretation of the participants' PCK for teaching lessons on osmosis and diffusion.

Each case profile begins with a vignette in which an overview of the participant's PCK for teaching osmosis and diffusion is presented in story form. In the vignette I attempted to capture the essential elements of the participant's practice and interaction with his/her students.

Each case profile includes the following sections reflective of the Magnusson et al. (1999) PCK model. The case begins with a vignette and continues with participant's orientation to science teaching, an overview of lesson plans for two consecutive days of instruction followed by participant knowledge of representations and instructional strategies, knowledge of students understanding of science, knowledge of assessment, and knowledge of curriculum.

Emma's Case Profile

Emma's Vignette: Make a Prediction

Emily directs her students, "Okay, I would like each lab group to pick up the eggs you placed in vinegar on Friday. Make sure you have your lab notebooks and something to write with, we are going to start the decalcified egg lab today."

After moving into the laboratory the students are seated in their lab groups with decalcified eggs still in beakers of vinegar. Emma states, "Take a few moments to look at your egg and think about how the egg has changed since Friday."

"Okay, just to review, tell me what you did with the eggs on Friday?" Emma asks as she studies their eggs.

"We found the mass of each egg and then we placed them in vinegar," a student tells Emma.

"Is there anything else that you did other than mass the eggs and place them in vinegar?" Emma asks.

A student in the back of the room says, "We predicted how they would look today after being in the vinegar over the weekend."

"Good. Look at the prediction you made about the eggs on Friday and look at the eggs today; think about your prediction and then think about how the eggs are now" Emma stated as the students studied their eggs.

"The eggs do not have a shell anymore," a student states. "Hey the eggs are bigger," another student responds. "Whoa! My egg broke! Like I was really careful but when I held the egg under water to rinse it off it broke," a student in the back shouts as he begins to clean the yolk off of the lab table.

Emma calls for students' attention: "Hey guys, why do you think the egg broke when he picked it up?" A student raises her hand and responds, "The eggs got really big when we soaked them in vinegar. They are all stretched out like balloons." Other members of her lab group agree with her.

"So why do you think the eggs got bigger?"

"Some of the vinegar moved into the egg and made it bigger and I bet it is heavier, too," a student in the back of the room replies.

"So tell me, what kind of data are you going to be gathering today when you observe and describe the changes in your eggs?" Emma asks as the students study their eggs.

A student, sitting at the back left lab table, responds, "We will use qualitative data."

Emma smiles and says "Good. So what will you write in your notebook if you are using qualitative data?"

After conferring with her lab group, a student jumps up and raises her hand, "I know this! We are going to write words, like descriptions of what the eggs look like and feel like and stuff like that." Her lab partners nod in unison.

"Good, your data will be describing what you see," Emma responds. "But you are also going to mass the eggs again today, what kind of data will you record when you do that?" Emma asks as she moves through the room watching the students work with their eggs.

Another student responds, "We will record numbers and that data is quantitative." Emma responds by complementing the student, "Good job."

“Have the masses of your eggs changed after soaking in vinegar?” Emma asks.
“How would you explain a change in the mass of the eggs?”

Students are massing their eggs on the balances in the back of the room. A student explains, “The mass of the eggs has increased and the eggs are bigger, like swollen but the shell looks like it is mostly gone.”

“Okay, so why do you think the eggs got bigger in the vinegar?” Emma asks. When there is no response, she directs students, “Talk to your lab partners.” The students discuss Emma’s question in their lab groups. Then the group at the center lab table says, “Well, we are not sure but we think that some of the vinegar must have gone into the egg and that is why the eggs are bigger.”

“That is very interesting” Emma comments. Emma then asks the students, “Well, if the egg became larger in vinegar, what do you think will happen to the egg when your lab group puts it into a beaker of corn syrup or a beaker of distilled water?” When the students do not respond, Emma states, “I want you to talk to your lab groups and come up with a prediction of what you think is going to happen to the egg you place in distilled water and the egg that you place in corn syrup. Remember to write your prediction in your notebook.”

Emma reminds her students, “We will test your predictions for the eggs tomorrow after the eggs have been in either distilled water or corn syrup.” Emma goes on to tell the students, “That is when we will know how the eggs have been altered by their environments.”

Background and Context

Emma, a woman in her thirties, genuinely enjoys teaching biology and working with high school students. She holds an undergraduate degree in biology and a master's degree in education. She is currently teaching tenth grade biology at Bing High School. Emma's teaching experience spans a total of eight years, five years as a part time high school biology teacher and, for the past three years, she has been a full time biology teacher at Bing High School.

Bing is small, rural mid-state community with a population of approximately 11,000 residents. The majority of the student population at Bing High School is White, with a minority population of approximately 16 percent (Department of Elementary and Secondary Education (DESE), 2009). Emma's classes consist of 18 to 22 students; this is consistent with the student/teacher ratio for the district (DESE, 2009). Emma's teaching facility consists of a traditional classroom and a separate room with a laboratory connected by a teacher preparation room. The traditional classroom contains five rows of student desks with a chalkboard in the front of the room. One computer located on Emma's desk. A data projector extends from the ceiling and is used for PowerPoint notes. There is limited storage within the classroom with cabinets located on the walls on both sides of the room. A teacher preparation room connects Emma's classroom to a laboratory room. In the laboratory there are six complete laboratory stations with sinks, running water, and gas jets. Emma is the only teacher assigned to this facility; therefore, the lab is open for use at any time. She is also the only teacher assigned to teach tenth grade biology at Bing High School.

Orientation to Science Teaching

Kagan (1992) posited that teachers' orientations act much like a filter through which teachers view and interpret teaching, learning, and learners. Thus, one's orientation to science teaching influences instructional decisions made during planning and teaching and references one's perceptions of the roles of teachers and learners as well as the purposes and goals for science teaching (Abell, 2007; Grossman, 1990; Handal, 2003; Magnusson et al 1999; Park & Oliver, 2006). I describe Emma's orientation to science teaching in terms of her: (a) goals and purposes of science education, (b) interpretation of teacher role, (c) interpretation of student role, (d) ideal images of teaching, and (e) view of science as a discipline.

Goals and purposes of instruction. Emma identified her overarching goal for teaching tenth grade biology as teaching students how to think. She consistently described her purpose in teaching as providing learning opportunities for students through which they can learn to think independently, explore biological concepts, construct knowledge of biology, and apply their knowledge to find answers to new questions. She explained, "I am really trying to teach them to think" (stimulated recall interview, Day2).

Emma's goal to teach her students to think; to achieve her overarching goal, Emma is focus on challenging her students to make and test predictions. On Day 1, Emma began the lesson by asking the students to predict what would happen to drops of food dye placed in a beaker of cool water. Emma told the students they would observe the beaker at the end of the lesson to test their predictions. On the previous Friday, Emma's students predicted potential changes in chicken eggs students massed and placed

in vinegar over the weekend. On the following Monday (Day 1), students observed the eggs and tested their predictions. They noted that the eggs had lost their shells, gained mass, and were notably larger in size. In each instance, Emma insisted that her students think about what they were about to do, predict what they thought would occur, and test their predictions by observing the outcome.

Emma designed her lessons to teach osmosis and diffusion by challenging students to apply their conceptions of osmosis and diffusion to develop a prediction for the decalcified chicken eggs placed in corn syrup or distilled water. Students tested their predictions through their observations of changes in the eggs, and data (change in egg mass and size) gathered during the investigation. Through this approach, Emma planned to teach her students to be independent thinkers. She then asked students to evaluate their predictions in terms of evidence gathered through observing and massing the eggs, and from that evidence develop an explanation of the outcome. Her overarching purpose was evident throughout both lessons. Emma explained her purpose by stating:

I want my kids to be independent thinkers. I want them to be able to think. I do not want them to just parrot what is on some lab sheet. . . .With every lab there is usually a dual purpose. Yes, I want them to learn about experimental design. Yes, I want them to record their data. Yes, I would really like it if they would get this [an accurate or expected result]. But I want them to realize that there is more than one way to get somewhere and I want them to think independently. (stimulated recall interview, Day 1)

Ultimately, Emma's goal was to support students as they constructed their knowledge of science. She challenged her students to construct their knowledge of osmosis their by making and testing predictions by noting and explaining changes in eggs placed within the two environments. She noted:

I thought that everyone was in a position to look at the egg and describe it and how it had changed. So I had hoped to get everyone on the same page and from

their descriptions try to figure out what is happening. Then the next piece would be to figure out which way the water was moving and then from there I wanted them to figure out why. But I was just trying to establish that this was the evidence that we had to work with and everybody's eggs are essentially the same so this is the place that we can begin to establish an explanation. They may use different words but essentially everybody's eggs looked the same. (stimulated recall interview, Day 2)

Emma was not focused on memorizing terms and definitions but rather consistently asked students to think about the rationale for their predictions and how their predictions would be tested. She focused on developing students' conceptual understanding of osmosis and diffusion.

Perception of teacher role. Emma's perception of her role as a teacher was to design instruction which challenges students to become "independent thinkers" (stimulated recall interview, Day 1). She wanted her students to think critically, answer questions, and apply their knowledge. This is a theme noted throughout both lessons.

During each day of the observation four of Emma's lessons were observed. Thus, Emma was observed teaching the same concepts to four different consecutive classes of tenth grade biology students. Clearly, in each class, even though there were differences in student ability levels and slight modifications in her instruction, Emma consistently exemplified the same focus for her teaching by asking students in each class to predict what would happen in terms of changes noted in decalcified chicken eggs related to the processes of osmosis and/or diffusion. Emma explained:

In each class there was a group struggling with their predictions. I just tell myself that I just need to walk away and let them puzzle it out. If I make that for them, they learn nothing. I might just as well have told them during a lecture what would happen and tell them to memorize that. I just have to remind myself not to do that and remind myself that we will figure it out tomorrow. (stimulated recall interview, Day 2)

On Day 1, Emma asked her students to predict changes in a beaker of water when several drops of food dye were added. Students were asked to record their prediction in their notebooks before Emma placed the food dye in the water. Students noted that the beaker which initially contained several drops of concentrated food dye and clear water was now a uniform color. Emma explained her focus on critical thinking by stating:

In my mind I am not teaching 150 biologists. These kids are going to be bankers, chefs, clerks and I want them to be able to think on their own in novel situations. I am trying to get them to think. (stimulated recall interview, Day 2)

Emma's perception of her role as a science teacher is to design lessons that challenge her students to think and apply their knowledge of biology to novel situations.

Perception of student role. Emma described her students' role as "being prepared to learn" (stimulated recall interview, Day 2). She believes that effective learning requires students to be active participants rather than passive entities taking notes and listening to explanations provided by the teacher. By designing lessons that require students to take on an active role, Emma indicated that she expects students to take responsibility for their own learning. Students should be prepared for class, maintain a science notebook, contribute to class discussions, make and test predictions for demonstrations or investigations, and collaborate effectively with their peers. For the lessons observed, students developed and tested predictions for a class demonstration and for the decalcified egg laboratory investigation. Prior to beginning the decalcified egg lab, students were responsible for developing a protocol from the laboratory handout provided the previous week. Students were not allowed to bring the handouts into class; they could only bring their notebooks to class to use as a guide for the investigation. Emma described the students' role:

Students must be active participants. They do not always choose to participate. I do not think that all of them are going to be highly successful as far as a letter grade assigned in my class. But I would like them all to do the activity, read the notes, and be an active participant in the class. I would like them to participate, to be responsible for their own learning, to try to grow for themselves. Other kids may grow more and other kids may grow less. But I want them all to take an active role. (stimulated recall interview, Day 2)

Clearly, Emma perceived the students' role in her classroom to be one of active participation. She consistently challenged her students to make and test predictions for phenomena observed during teacher demonstrations and student investigations. Emma believes that students must take responsibility for their own learning.

Ideal images of teaching. Emma's ideal image of teaching involves engaging her students through investigations that are both interesting and important in terms of teaching content. In her ideal lesson she imagines her students as actively engaged and excited about learning. Emma described her students' behavior during her ideal lesson as being actively engaged in learning, asking questions, collaborating with peers to find answers for questions, and developing new questions for future investigations.

You know in a perfect day, it is something that they are interested in and that they are excited about and they got to see the concept either in a demonstration or in a lab that they got to do themselves. Everything made crystal clear sense. We talked about it and we talked about the concepts and they understood and you know, so I do not know if I have an exact method but in an ideal world they are seeing or doing something and they are able to understand it and apply it to a novel situation. (stimulated recall interview, Day 2)

Emma explained that it is easier to teach through a traditional, teacher-directed format that is focused on lectures and PowerPoint notes. However, she noted that even though lesson preparation might be easier, it is not necessarily the best way for students to learn.

Emma explained:

You know I like labs; it is way easier to prepare a lecture. I mean I can type out PowerPoint at the speed of light and I can make diagrams. That is definitely

easier. I might think that it works but I do not think that it is the best way for the students to learn. So lectures are the easier way to teach but it is not the best way for them [the students]. Lecture does have value but they really must be doing to be learning. (stimulated recall interview, Day 2)

Emma's ideal images of teaching involves engaging students in activities which challenge them to think critically, make and test predictions, and identify evidence that can be used to support explanations. Emma's vision of effective teaching guides her thinking during planning and teaching.

View of science as a discipline. Emma perceives science as a way of knowing rather than a body of related and unrelated facts about living things. She explained that she wants her students to understand that science is based empirical evidence gathered through investigations designed to find answers to questions about the natural world. To accomplish her purpose, she developed learning opportunities for her students to make and test predictions, gather and interpret data, use evidence to defend or refute predictions, and provide explanations based upon evidence gathered during their investigation. Emma explained:

I think that it is valuable for them to know that science is really based upon investigation and you can make two kinds of observations. You can base your observations on what you see and use words to describe your observations or you can get some really nice concrete data. You can use numbers if you are making measurements or use color changes. (stimulated recall interview, Day 1)

Emma's focus on qualitative and quantitative data indicates that she clearly understands the importance of evidence within the context of science. She explained: "I pull it out because I think that it is really important and they use it [qualitative data and quantitative data] in every day life" (stimulated recall interview, Day 1).

Emma's perception of scientific knowledge as knowledge gained through investigations and conclusions supported with evidence is underscored by her

involvement with Partnership for Research and Education in Plants (PREP). Through this program Emma challenges her students to design their own experiments using wild type and genetically altered *Arabidopsis thaliana* seeds provided by a partner plant scientist from the university. The goal for student research is to characterize the function of the mutated gene by noting differences between the mutant and wild type plants grown under identical environmental conditions. Emma noted:

They need to be able to do those things and mainly do a performance event. I have been trying especially after the conference that we went to with PREP which Christine came to. I got two really big things out of that conference. One was how to design experiments in your classroom. Teaching experimental design was another. There are graphs that I am trying to focus on like making really nice graphs. I thought that this was a nice time to make graphs and they [the students] obviously needed a review. (stimulated recall interview, Day 1)

Emma views science as a discipline that demands evidence and consistently challenged her students to support their explanations with evidence gathered during the investigation with decalcified eggs. She believes when students identify and gather evidence to support their explanations the evidence becomes personal and enhances their understanding of the concepts taught through the investigation.

It is really important because it is their evidence. It becomes personal for them and they will say 'My egg did this.' I think that it gives them something concrete to latch on to that will hopefully help them to remember rather than just remembering an experiment they did. So I think that providing evidence is very important. (stimulated recall interview, Day 2)

Emma's views of science are reflected in her teaching. She emphasized the importance of evidence to her students by challenging them to support their claims and assertions with evidence gathered during investigations. By doing so, she has created a learning environment which encourages questioning, investigating, and explaining ideas with supporting evidence.

Summary of Emma's orientation to science teaching. Emma identified her experience teaching high school biology in a small, rural community; completing a Master's Degree in Science Education; and working with a university sponsored program supporting student-driven research with plants as important sources of her goals and purposes for teaching science. She explained, teaching in a small community increased her interaction with parents and district administrators; however, because she is the only tenth grade biology teacher, she described herself as an "island" (pre-observation interview). Emma explained she found a community of professional teachers within the context of a university program, Partnership for Research and Education with Plants (PREP). She noted her collaboration with other teachers through PREP changed her beliefs about teaching and learning. Emma noted she engages students in explorations of phenomena to make them active participants in the learning process and support the construction of a framework to make sense of new concepts. Explanations are developed from students' ideas, observations, and data from explorations. Figure 5 illustrates the sources informing Emma's orientation to science teaching.

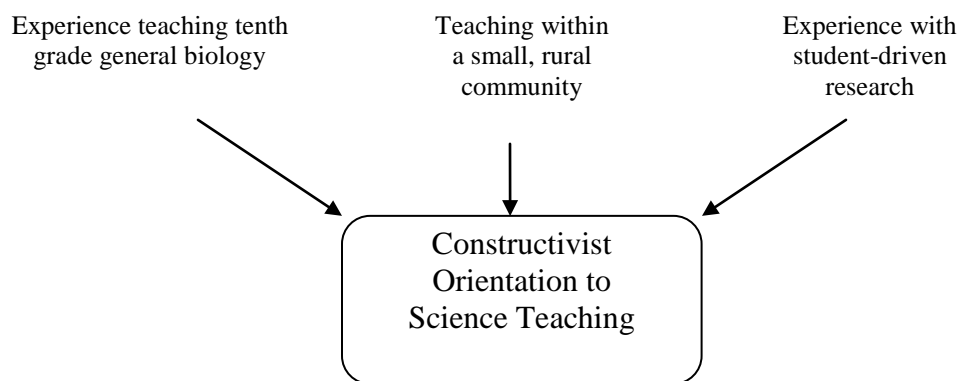


Figure 5: *Sources of Emma's orientation to science teaching*

I describe Emma as having a constructivist orientation to science teaching for the following reasons. First, Emma designed lessons with an implicit 5E instructional sequence and initially engaged students in explorations of phenomena in which students made observations and recorded data. Second, she challenged students to predict outcomes and test their predictions with their observations and data. Emma challenged students to support their claims with evidence taken from the exploration. Third, Emma drew upon students' explanations and observations to support the construction of new knowledge and helped students make connections between their prior ideas and new ideas and explanations. In sum, Emma engaged actively engaged students in explorations of phenomena and supported them as they made sense of new ideas by reflecting on their experiences with the phenomenon.

Lesson Plan

In this section, I provide a detailed overview of Emma's lesson plans for the two consecutive days of classroom observation. On Day 1 of Emma's lesson (see Table 10), she began with a brief review of the structure of the cell membrane. She engaged students by calling them to the board to draw and label diagrams of the cell membrane and note the polar and nonpolar regions of the membrane. The lesson continued with a demonstration illustrating diffusion; Emma placed several drops of food dye into a beaker of cold water and challenged students to predict the condition of the beaker contents at the end of the lesson. Next, the students move into the laboratory where they set up an investigation examining the changes in decalcified eggs placed in corn syrup and distilled water.

Table 10. *Emma's lesson plan for Day 1*

	Activity		Description
Day 1	Review	Engage	Teacher: <ul style="list-style-type: none"> • Initiates the lesson with a brief review of the cell membrane • Four key terms are emphasized: solute, solvent, concentration, and plasma membrane
	Diffusion demonstration - drops of food dye are added to a beaker of water	Explain	Teacher: <ul style="list-style-type: none"> • Challenged to predict changes likely to be observed after food dye is added to the water Students: <ul style="list-style-type: none"> • Explain the rationale behind their predictions
	Laboratory investigation - <ul style="list-style-type: none"> • removed decalcified eggs from vinegar, observed, and massed • placed in corn syrup or water 	Elaborate	Students: <ul style="list-style-type: none"> • Removed decalcified eggs from vinegar • Observe decalcified eggs • Mass eggs, and record data in laboratory notebooks • Draw upon their knowledge of osmosis and diffusion to predict changes in the egg resulting from reversing placement of the eggs into distilled water or corn syrup
	Observation - Diffusion demonstration	Explain	Teacher <ul style="list-style-type: none"> • Challenges students to explain their observations of food dye and water Students <ul style="list-style-type: none"> • Observe food dye in water to test their predictions • Explain observations in terms of diffusion

A similar instructional sequence was observed during Day 2 (see Table 11) of the observation. Emma began the lesson by asking students to observe the eggs after students had placed them in distilled water or corn syrup on Day 1. She encouraged her students to think about the changes observed in the eggs in light of their predictions made the previous day. She challenged them to explain the outcome of the investigation through the movement of water into or out of the eggs within this model of osmosis.

Table 11. *Emma's lesson plan for Day 2*

	Activity		Description
Day 2	Students collect and observe decalcified placed in distilled water and corn syrup on previous day	Engage	Teacher: • Engages students in observation of eggs Students: • Observe eggs, test predictions with quantitative and qualitative observations
	Recording data	Explore	Teacher: • Guides students in development of data table Students: • Record ending masses of decalcified eggs • Develop table designed for recording qualitative observations
	Testing predictions	Explain	Students: • Compare egg masses and observations to test predictions • Develop explanations for changes observed in decalcified eggs • Share predictions and explain observed results in light of osmosis and diffusion

Emma's lesson plans indicate her strategy was to engage students with a demonstration illustrating diffusion on Day 1 and in an investigation into osmosis in which decalcified eggs placed in two unique environments [distilled water and corn syrup] either gained or lost water. On Day 2, Emma challenged students to observe changes in the decalcified eggs and test their predictions from Day 1. Students applied knowledge of diffusion and osmosis to explain changes observed in the decalcified eggs. Emma also stressed that students' explanations be supported by evidence gathered on Day 1 and Day 2 of the investigation.

In the following sections, I describe Emma's knowledge for teaching diffusion and osmosis in terms of the Magnusson et al. (1999) components of PCK including: knowledge of representations and instructional strategies, knowledge of students as learners, knowledge of curriculum, and knowledge of assessment.

Knowledge of Representations and Instructional Strategies

During the pre-observation interview Emma was asked about the representations and instructional strategies she planned to implement to teach the concepts of osmosis and diffusion. Emma planned to implement several representations of diffusion, osmosis, a living cell, and semipermeable membranes into the lessons on Days 1 and 2 including: (1) drops of food dye placed in water to represent diffusion, (2) an acrylic model of the semipermeable cell membrane, and (4) decalcified eggs as a model of a living cell surrounded by a semipermeable membrane. The instructional strategies Emma intended to implement include: (1) teacher demonstrations, (2) laboratory investigation as a means of discovery in which students would make and test predictions of the outcome, and (3) whole class discussions. Emma noted her preference for laboratory investigations to help students learn but time was often a serious constraint.

On Day 1, Emma introduced diffusion through a demonstration in which she placed a drop of food dye into a beaker of cold water; she directed students to predict changes likely to take place within the beaker of food dye and water during the class period. Emma explained that she chose this representation because it focused students on the movement of substances along a concentration gradient [from higher to lower concentrations], thus, setting the foundation for an investigation into osmosis.

A plastic model was introduced as a representation of a semi-permeable cell membrane. The model consisted of a clear plastic box in which larger red beads and smaller white beads were housed. The box was divided diagonally by a plastic divider with holes large enough for the white beads to move through but too small for the red beads. Thus, the white beads could move from one side of the model to the other while

the red beads were contained in only one side of the model. Emma used this model to reinforce student comprehension of the concept of semi-permeable membranes.

The third representation consisted of decalcified chicken eggs which were the focus of the laboratory investigation conducted on Days 1 and 2 of the observation. Decalcified eggs were implemented as representations of a living cell and a semipermeable cell membrane. The egg shells had been dissolved through exposure to vinegar, leaving the eggs surrounded only by a semipermeable membrane. Before placing the eggs in beakers of distilled water or corn syrup, students massed and predicted changes in the decalcified eggs within each environment. Students tested their predictions by observing changes in the decalcified eggs on Day 2 of the observation. The egg placed in corn syrup had lost mass; the shriveled appearance indicated significant water loss. Water diffused out of the egg into the highly concentrated corn syrup environment in the beaker, leaving the egg shriveled. In contrast, the egg in distilled water doubled in size as water diffused into the solute rich environment within the decalcified egg. Aware of the importance of representations illustrating scientific processes, Emma questioned the need for additional models of osmosis as concrete representatives of osmosis. Emma explained:

I think that the model from the egg lab is good; I mean I think that it is really clear. I think that [the egg lab] is one example. Is one example enough? If it is a new concept, one example is not enough. Obviously it is not sufficient; they need more concrete examples. They need more things that they can manipulate and see or whatever. (stimulated recall interview, Day 2)

During Day 2, several students struggled to develop an explanation for the changes observed in the decalcified eggs. They did not seem to understand why the eggs changed so drastically after being placed in the corn syrup or distilled water. Emma

responded by using the chalkboard to draw diagrams of decalcified eggs in two beakers, one containing corn syrup and the other containing distilled water. Emma's diagram is shown below in Figure 6.

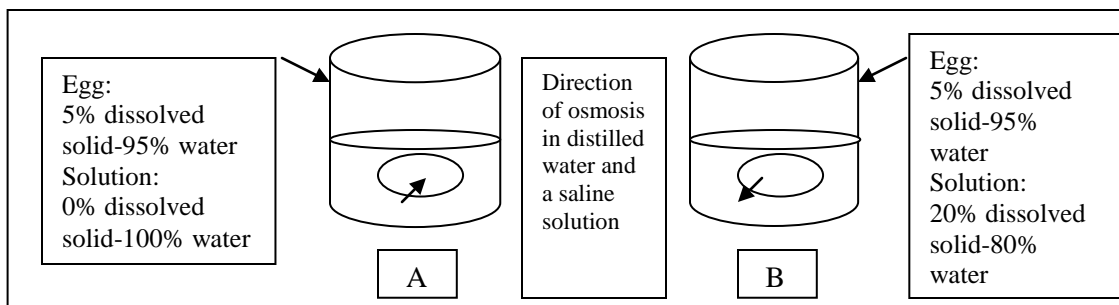


Figure 6: Diagram of decalcified eggs in distilled water (A) and in corn syrup (B)

Emma estimated percentages of dissolved solid within the egg and the corn syrup solution and distilled water within the diagram (see Figure 6). Students subtracted the percentage of dissolved solid from 100, to determine the relative percentage of water within each solution [the solution in the decalcified egg and the solution within each beaker]. Next, Emma challenged the students to use the relative percentages of water to draw arrows indicating the direction of osmosis in the diagram. Emma explained: “They [students] will be able to say that it is all relative and it depends upon the concentration of the cell relative to the concentration of the environment” (stimulated recall interview, Day 2). By using the chalkboard, she was able to progress from students collaboration with lab partners to a whole class discussion focused on the direction of osmosis in different environments. When asked why she decided to use the chalkboard, she explained that she was trying to give the students a different perspective of the investigation to enhance their understanding. Emma noted:

I was trying to give them something else to look at. Like I said before, the models would be better but at least it was something else to look at besides a fat egg and a

deflated egg. I was trying to get them to think and to make some comparisons. (stimulated recall interview, day 2, page 16)

Other topic-specific representations Emma implemented included analogies to provide students with representations that connected the concepts of osmosis and diffusion to students' prior knowledge and experience. Emma made connections between fresh water and ocean water by using what she referenced as an ocean analogy. Students' knowledge of ocean water was revealed when Emma asked students if ocean water could be consumed instead of fresh water. Several students responded that ocean water could not be consumed because of its high salt content. To explain why ocean water would be detrimental to cells, Emma used an example of a single cell placed in a beaker of ocean water. She identified relative concentrations of dissolved solids (e.g., Epsom salts, potassium salts, and iodine salts) found in ocean water and within the cytoplasm within the cell. She reminded students the concentration of water could be extrapolated from the concentration of dissolved solid within each solution; higher concentrations of dissolved solids indicated lower concentrations of water and lower concentrations of dissolved solids indicated higher concentrations of water. Next Emma challenged students to predict the direction of water movement. Students, reflecting upon the earlier discussion, indicated that water would likely leave the cell and move into the ocean water within the beaker. Emma explained that even though the cell was in water, the cell would become dehydrated due to the highly saline environment within ocean water; thus, water would move from higher to lower concentrations across the plasma membrane. Emma believed the ocean water analogy made important connections between students' prior knowledge and experiences and supported students' comprehension of the decalcified egg laboratory investigation. She explained:

I ask them what their skin feels like when they get out of the ocean and they tell me that their skin feels dry and itchy and their lips are chapped. They tell me to feel better after they rinse off with plain water and get a drink. We talked about where the water from your cells goes. If your cells are dehydrated from drinking ocean water or just from being in the ocean where did that water go? They then tell me that the water from their cells went into the ocean. They then begin to think about the water from their cells going into the ocean. The notion that water will be lost from cells when the cells are placed in a hypertonic solution is what I want them to see and to do that I use the analogy about the ocean. Then they can relate to it. (pre-observation interview)

Emma explained that she is continually searching for representations and laboratory investigations to implement into her instruction. She explained, “I think I am like the students or most of my students are like this. I want some sort of manipulative; it might be a model or it might be something that I can actually do or whatever” (stimulated recall interview, Day 2).

Emma implemented multiple instructional strategies into her instruction. She initially relied upon a brief discussion emphasizing four key terms: solute, solvent, concentration, and solution. Emma noted the terms, related to osmosis and diffusion, prepared students for the laboratory investigation. Emma explained:

To understand what we are going to be talking about there are four words that are a review from physical science, that you will need to understand and those words are solute, solvent, concentration, and solution.’ So when I talked about that we talked about concentration expressed as a percent. (stimulated recall interview, Day 2)

She implemented a cooperative laboratory investigation into osmosis and diffusion. Within the context of the investigation, Emma required students to make and test predictions forecasting changes in the eggs resulting from placement in a specific environment [distilled water or corn syrup]. Emma explained:

I am going to give them time to look at their eggs and make some observations. They will have a chance to look at their eggs and we will talk about why that happened [the eggs decalcified in a vinegar solution]. And then they should take

some quantitative measurements and actually weigh their egg and record that, they have a lab notebook that they are keeping and they will record that. (pre-observation interview)

When students made and recorded observations, Emma required students to distinguish between qualitative and quantitative data and design tables or charts to record each in their laboratory notebooks. She believes that when students carefully record their observations, the data takes on greater meaning and becomes their data rather than an activity completed in class. She explained:

It is really important because it is their evidence. It becomes personal for them and they will say, “My egg did this”. I think that it gives them something concrete to latch on to that will hopefully help them to remember rather than just remembering an experiment they did. So I think that providing evidence is very important. (stimulated recall interview, Day 1)

Emma relied heavily upon representations to illustrate osmosis and diffusion in each of her lessons. When students experienced difficulty understanding the direction of water movement into or out of the eggs, she used the chalkboard to develop a new representation. Emma relied upon a cooperative laboratory investigation to challenge students to think about osmosis and diffusion in living systems and share their thoughts with members of their team. Students were challenged to make and test predictions while whole class discussions provided students with a means of sharing ideas between lab groups. Students’ claims and conclusions were to be supported with evidence.

Knowledge of Students’ Understanding of Science

Emma explained students learn best when they are actively engaged in learning. She noted, “I would like them to participate, to be responsible for their own learning, to try to grow for themselves.” (stimulated recall interview, Day 2)

In the pre-observation interview, Emma's predicted students would have difficulty making the connection between the relative concentration of dissolved solids within the egg and that of the surrounding environment to accurately predict the direction of osmosis. Emma believed if students were confused about relative concentrations of dissolved solid and water within solutions they would not be able to accurately predict the direction of water movement during osmosis. Emma was concerned that vocabulary terms associated with osmosis and diffusion (hypertonic, hypotonic, and isotonic) were foreign and might present difficulty for her students, creating more confusion than meaning. She explained:

I think that they might struggle with this particular concept [tonicity], the surrounding solution. Is it hypertonic, hypotonic, or isotonic? Once they figure it out, they can predict which way it will go. It is hard to predict, I do not know how it will go with this group. We have just kind of started. But that is one area [vocabulary] where I think that they might struggle. (pre-observation interview)

Emma introduced vocabulary terms during discussions of students' observations, relating terminology to students' experiences with osmosis.

Explaining students often hold misconceptions about forces determining the direction of osmosis, Emma noted students made inaccurate predictions of the direction of osmosis when asked how the eggs would respond if the placement were reversed. She explained, "I was very surprised to hear some groups predict that the same thing would happen to both eggs even though they were placed in very different solutions" (stimulated recall interview, Day 1). To address this misconception, Emma directed the students to reverse the placement of the eggs and make and test predictions of how the eggs would change.

Emma judged the success of her lesson upon the degree to which her students were engaged in learning. During the first day of observation, students predicted the outcome of a diffusion demonstration and followed the protocols they had written in their lab books to set up an experiment in which decalcified eggs would be placed in two different solutions (distilled water and corn syrup). After massing the eggs, students predicted the impact of each environment on the decalcified eggs. One aspect of Emma's response to student learning is that she did not focus upon the accuracy of their predictions but rather on the level of their engagement in thinking about what would happen as the eggs remained in each solution overnight and on explaining their ideas. So her focus was more on the processes of science rather than on the accuracy of students' predictions. Emma explained:

I think that it went pretty good, I mean students, they were involved, they were engaged in what they were doing. They were asking questions, answering questions, they were recording results. They were taking notes. They were making predictions; some of the predictions were accurate and some were not. But that is not the point. So I think it went pretty well. (stimulated recall interview, Day 1)

When asked about her reasoning for having students make predictions about water movement into or out of the decalcified eggs, Emma explained that making predictions captured student interest and made the outcome of the investigation a more important aspect of their learning. She noted:

I do not know if they will understand by tomorrow what was wrong with their prediction but I think that they will clearly see what did happen and I think that they will at least begin to put together that the movement of the molecules is determined by the relative concentrations of the solution outside of the cell. (stimulated recall interview, Day1)

Emma noted that students may experience difficulty with vocabulary terms and taught the concepts before introducing vocabulary. She noted students experienced less

difficulty with vocabulary when students explored the phenomena first. Emma believed her students demonstrated greater understanding of the concepts and the meaning of vocabulary. Emma noted:

In the past, I went to vocabulary terms and then tried to apply those terms to the eggs. Today, I went from students' descriptions of their eggs, to diagrams of the eggs, and then I went from the eggs to terms [hypertonic, hypotonic, isotonic]. I think today was better. (stimulated recall interview, Day 2)

Emma believed that she could enhance students' understanding by implementing another representation to illustrate the importance of relative concentrations of dissolved solid within the decalcified egg and the surrounding environment to determine the direction of water movement. She explained:

It is the concentration gradient that will determine what direction the water will move [into the cell in a hypotonic environment and out of the cell in a hypertonic environment]. Then maybe that would help them make that connection. So then maybe I need to give them a new situation they would be more likely to get the idea and understand direction of movement. (stimulated recall interview, Day 2)

Emma wanted students to perceive molecular motion as the driving force for osmosis and diffusion. On the following day, she intended to implement a different version of the diffusion demonstration. The new diffusion demonstration would identify the temperature of the water as a factor in the rate of diffusion. Emma believed she could focus students' thinking on the concept of molecular motion as the driving force for diffusion and osmosis. She noted:

I think that tomorrow I think that I am going to try the food coloring demonstration in water with different temperatures to investigate molecular movement. An investigation in which lettuce would be used in distilled water and in salt water and then tomorrow, I thought we would switch the eggs and place the egg that was in corn syrup in distilled water and the egg that was in distilled water in corn syrup. (stimulated recall interview, Day 2)

Emma believed students learn most effectively when they are actively engaged in the learning process and noted that students may struggle with vocabulary terms such as hypertonic, hypotonic, and isotonic. To avoid this confusion, she focused on students' conceptual understanding rather than comprehension and retention of vocabulary terms and definitions. Emma believes that students will develop a conceptual understanding of biological concepts if they are engaged as active participants in doing science and applying their knowledge to novel investigations or problems.

Knowledge of Assessment

Emma explained her plans to elicit student thinking about osmosis and diffusion by challenging students to make and test predictions, asking students questions, and monitoring students' questions and answers to determine conceptual understanding. During both lessons, she relied upon questioning as a means of a formative assessment when students were working in collaborative teams and during whole class discussions. When asked how she would use that information, she explained that if students' answers indicated a lack of conceptual understanding she would focus on the more basic aspects of the concept to find a baseline for student understanding. Emma explained:

I think that I will go backwards in my questioning and try to pull out basic stuff first. Like go back to last week and pull out some learning from last week like vocabulary and basic concepts first. Once I make sure that those [concepts related to the tonicity of solutions] are in place then go back and ask the questions. Today I do not know if they will be able to piece it all together because they will not be able to see. The egg will be swollen because it has been in a vinegar solution but it will not be as dramatic as it will be tomorrow after the eggs have been in distilled water and corn syrup. I do not know how far we will get but I will try to use some questions and go backwards until they can apply their understanding of osmosis and diffusion to the lab. (pre-observation interview)

Emma relied upon feedback from formative assessments to inform her teaching.

For instance, she used student predictions to evaluate understanding of key concepts.

Emma assessed students' understanding of diffusion and movement of a substance along a concentration gradient by asking them to predict how drops of food dye would behave in a beaker of cold water. A similar formative assessment strategy was implemented when students were asked to predict the movement of water when decalcified eggs were placed in corn syrup or distilled water.

Emma noted that during Day 2 of the observation, students in her fifth hour class made incorrect predictions indicating that they did not understand the direction of water movement into or out of the decalcified egg in distilled water or corn syrup. Emma explained:

I was very surprised to hear some groups predict that the same thing would happen to both eggs even though they [the eggs] were placed in very different solutions. It is like they are predicting that tomorrow whatever they will see in the egg that is in distilled water they will see the same thing in the egg that is in corn syrup. (stimulated recall interview, Day 2)

Surprised by students' incorrect predictions, Emma took action to resolve student confusion by drawing a diagram of the decalcified eggs in two different solutions on the whiteboard and reviewing the meaning of the terms solute and solvent (see Figure 6). She used solute concentration to determine the relative concentration of water within the eggs and the surrounding environments. Emma asked students to consider the relative concentrations of dissolved solid in each environment and predict the direction of osmosis. Without using the term "concentration gradient" Emma used the percentage of water in the egg and the surrounding environment to lead students to accurately predict water movement. She often asked students questions to gain greater insight into their thinking and used that knowledge to craft meaningful and effective explanations. She explained, "I definitely think that I was using formative assessments. I was either asking

for them to raise their hand if they saw it a certain way so I got a picture of what they thought” (stimulated recall interview, Day 2).

After noting student confusion about the direction of water movement, Emma decided to have students in her fifth hour class reverse the placement of the eggs. She explained that when students saw the changes in the eggs they would have a better understanding of the movement of water along the concentration gradient even if the explicit term had not been used. Emma explained:

I am hoping that they [the students] will look at today’s results versus tomorrow’s results and they will be able to make a comparison and think about what happened. They will be able to say that it is all relative and it depends upon the concentration of the cell relative to the concentration of the environment. (stimulated recall interview, Day 2)

Emma utilized laboratory notebooks as a tool for students to record their predictions, observations, and data from the decalcified egg investigation. She believes students can use notebooks to help them think about the investigation protocol and how the changes in the decalcified egg reflected the direction of osmosis. Emma explained students’ lab notebooks were helpful as a formative assessment tool and noted she could assess students’ conceptual understanding of the phenomena by reading their explanations and ideas. She explained:

I think that it helps them to think about what they are doing and why they are doing it instead of thinking in terms of step 1 and step 2. They did get a prepared lab for the decalcified egg investigation and they just rewrote it in their own words. (pre-observation interview)

The actions Emma took to resolve student confusion indicated her ability to use feedback from formative assessment to inform her instruction. Emma used formative assessments embedded in her teaching to guide the next steps in her instruction. For example, when Emma noted that students were confused about the direction of water

movement following the investigation, she decided to have students reverse the placement of the decalcified eggs. Thus, she was able to assess student comprehension during instruction and take corrective steps when necessary.

Knowledge of Curriculum

When asked how the topics of osmosis and diffusion fit into the curriculum, Emma responded with an overview of her tenth grade biology curriculum. She related the concepts of osmosis and diffusion to cells and cellular function investigated earlier during the fall semester. She explained that water balance in all organisms is regulated by solute concentration and osmosis:

It [osmosis and diffusion] fits in because our previous learning was on cells. Cells are the basic structural and functional units of life. How will those cells carry out the functions of life unless they can get raw materials into the cell to work with and unless they can get rid of waste? Also how will the cells get their products out to go elsewhere into the body? So it fits in with past learning there. (pre-observation interview)

Emma noted that osmosis and diffusion form a conceptual basis for students' understanding of photosynthesis and cellular respiration taught during the winter semester. Emma explained that osmosis and diffusion is typically covered during the fall semester:

So it fits in with future learning, this as far as we will get before Christmas, but after we get back we will kind of review and go on into photosynthesis and cellular respiration. Of course, osmosis and diffusion will be important for those topics. So then we will be working with our plants at the same time and then that will lead into genetics which is kind of where we finish before the test. (pre-observation interview)

Emma noted the importance of lesson sequence and explained she engages students with an exploration of phenomena prior to generating explanations. Students' explanations

resulted from observations made during investigations and supported with evidence taken from the investigations.

Emma explained that her biology curriculum is largely determined by the state and the school district. The Missouri Course Level Expectations (CLEs) and End of Course Exam would determine the content students would be expected to know. The school district science curriculum, shaped by the state CLEs, also has a significant influence on the biology curriculum because students will enroll in other science courses in which specific content knowledge would be expected. For example, when students enrolled in Advanced Placement Biology they would be expected to know basic cell structure and function. Emma emphasized the importance of state standards and district curriculum when developing her syllabus. She explained that daily lesson planning emphasized content knowledge stressed by state CLEs and the district curriculum.

Emma's PCK for Teaching Osmosis and Diffusion

There are two models for Emma's PCK addressed in this section. First, the Magnusson et al. (1999) model of PCK has been adapted to illustrate the nature of Emma's PCK for teaching osmosis. Emma's PCK for teaching osmosis and diffusion is shown in Figure 7. Emma's PCK model notes the relationship between her orientation to science teaching and the components of her PCK.

Emma's overarching goal for teaching science is to teach her students how to think independently. She believes that effective learning takes place when students are active participants engaged in asking questions and finding answers and that her role as the teacher is to plan lessons that actively engage students in learning science. Emma has

a constructivist orientation to science teaching. A model of Emma’s PCK for teaching diffusion and osmosis is shown in Figure 7.

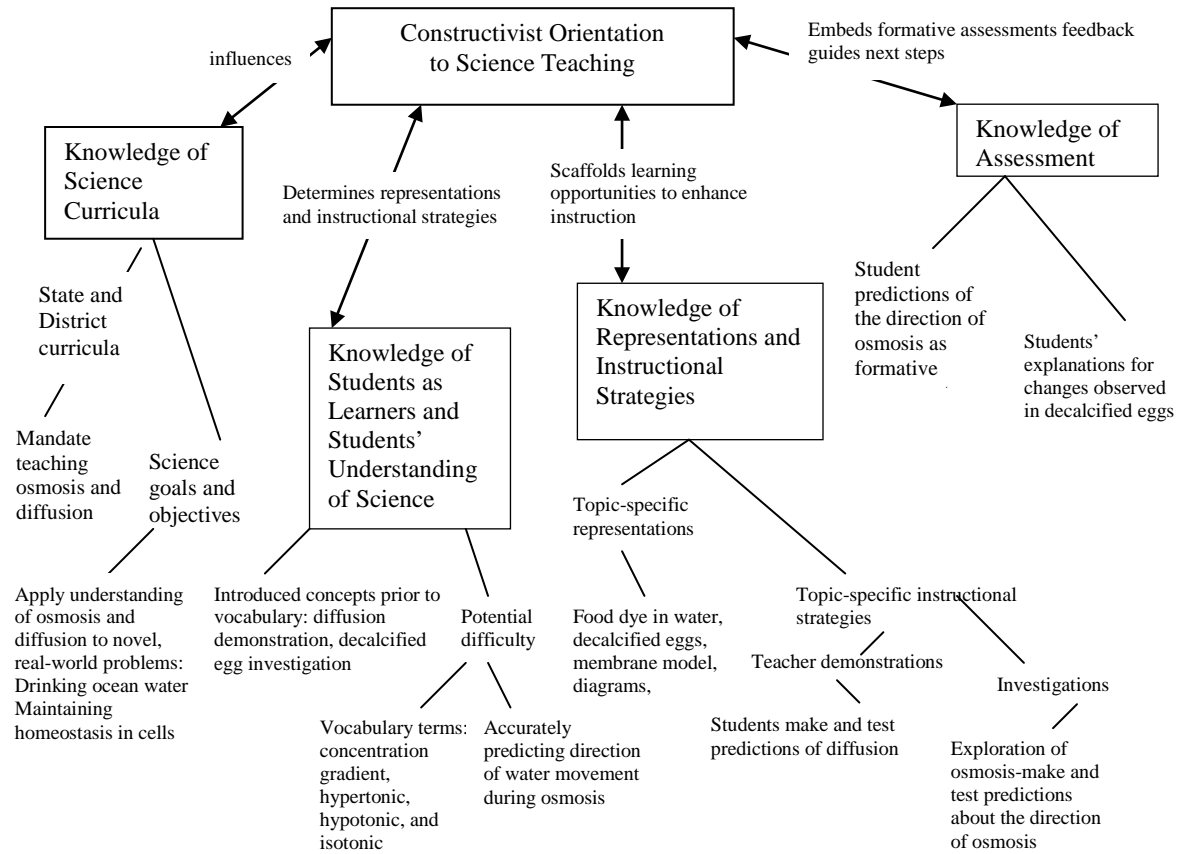


Figure 7: Emma’s topic-specific PCK⁷

Emma’s beliefs about teaching and learning acted as a filter in shaping the nature of representations, instructional strategies and sequence of instruction implemented within her lessons. Her sequence of instruction was reflective of the 5E instructional model (Bybee, 1997) in that she initially engaged students with an exploration of the

⁷Note. Modified from Nature, sources, and development of pedagogical content knowledge for science teaching (p.99), by S. Magnusson, J. Krajcik, & H. Borko, 1999. In J. Gess-Newsome & N. G. Lederman (Eds.), Examining pedagogical content knowledge. Boston, MA: Kluwer.

topic prior to an explanation. Hence, Emma's beliefs about learners and knowledge of potential student learning difficulties associated with osmosis and diffusion informed the sequence of introduction of concepts, vocabulary terms, and definitions. Emma noted vocabulary terms such as hypertonic, hypertonic, isotonic, and concentration gradient would be difficult for students and interfere with conceptual understanding of the processes of osmosis and diffusion. Thus, she introduced the concepts of diffusion and osmosis prior to introducing vocabulary.

A second model of Emma's PCK represents the integration of the components of her PCK embedded within Emma's orientation to science teaching. Emma's PCK for teaching diffusion and osmosis, shown in Figure 8 and represents the integration of the components of teacher knowledge specific for teaching diffusion and osmosis. There are four important features to note within this representation. First, Emma's orientation to science teaching is placed within the center of the model indicating the centrality of her orientation for the integration of PCK components during planning and teaching. Second, connecting arrows between components indicate connections between components creating knowledge specific for teaching diffusion and osmosis. Third, brief descriptions of Emma's knowledge of the components of her PCK provide insight into her knowledge of teaching, learners, and learning. Fourth, brief connecting statements between components demonstrate Emma's integration of knowledge for teaching diffusion and osmosis.

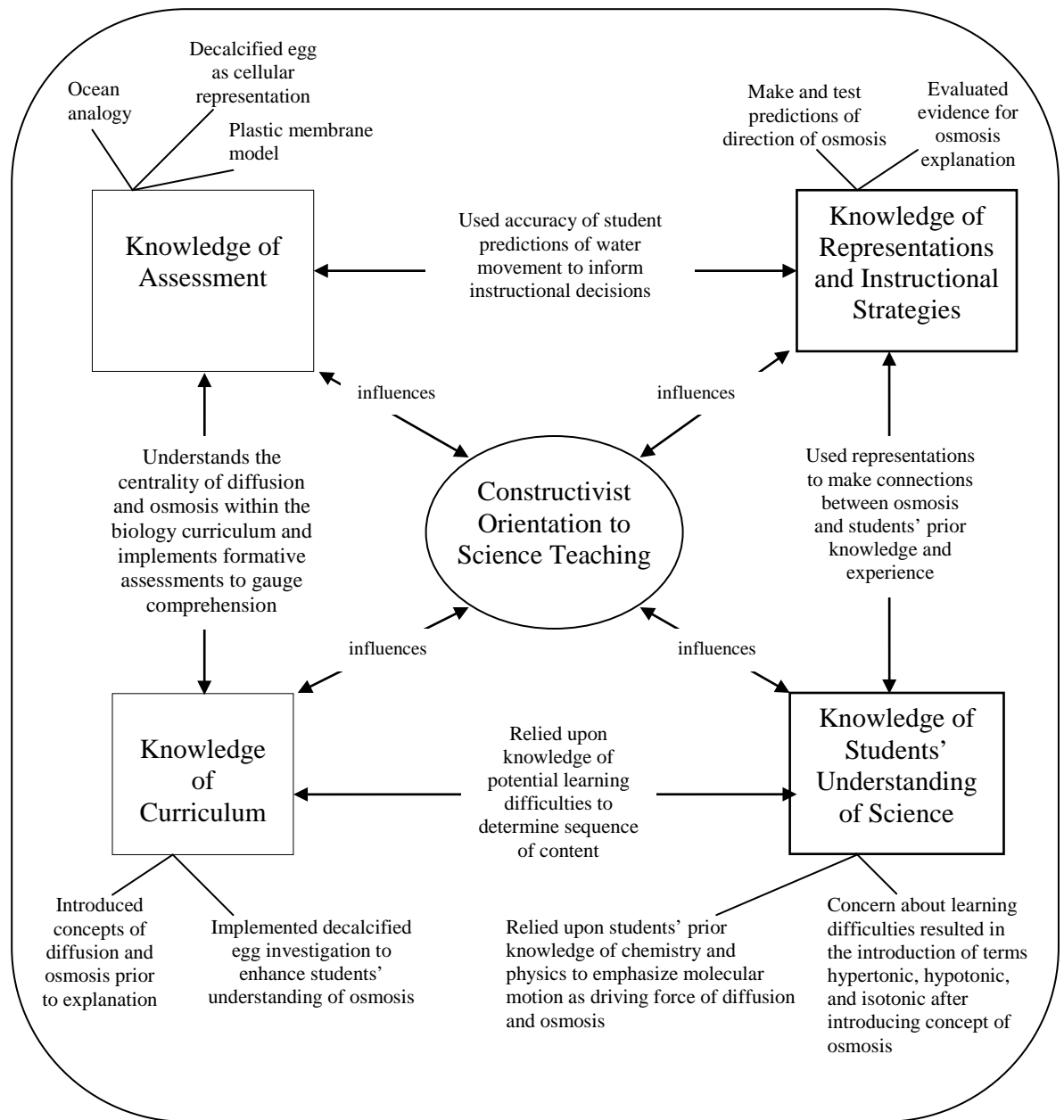


Figure 8: *Integration of Emma's topic-specific PCK*

Because she believed students would have difficulty predicting the direction of water movement during osmosis, Emma drew upon her knowledge of representations and instructional strategies to identify decalcified chicken eggs as a representative of a living cell and the focus of an osmosis laboratory investigation. To gauge students' comprehension, Emma challenged students to make and test predictions; she posed

questions during the investigation and subsequent class discussions as formative assessments of students' conceptual understanding. Emma's knowledge of curriculum guided her decision to introduce the phenomena first. Her understanding of the vertical and horizontal curricula informed her understanding of students' prior knowledge based upon district science curriculum and the availability of curricular resources. Connecting arrows between the components of Emma's PCK indicate the highly integrated nature of Emma's knowledge. Emma's constructivist orientation for teaching biology informed the implementation of an implicit 5E instructional model (Bybee, 1997). She drew upon all four components to create learning experiences to support students as they constructed their knowledge of osmosis and diffusion.

Content Representation

Descriptions of teacher knowledge can be found throughout education literature; however, specific examples of teacher knowledge that actually inform instructional decisions during planning and teaching are more difficult to identify. Loughran et al. (2004) and Loughran et al. (2006) suggest that the knowledge of teaching possessed by teachers can only be clarified when teacher thinking can be revealed and understood. Loughran et al. (2006) have developed a means of documenting concrete examples of teacher knowledge. The Content Representation (CoRe) is used to assess multiple aspects of teacher knowledge including content knowledge, the goals and purposes of the lesson, the instructional strategies and representations to be implemented within the lesson, and the means of assessing student understanding during the lesson (Loughran et al. 2006; Loughran et al. 2004). Thus, a window can be opened into teacher thinking to investigate

how the components of teacher knowledge are drawn upon when teachers make instructional decisions during planning and teaching.

In Table 12, a CoRe illustrates Emma’s knowledge of teaching osmosis and diffusion. The components of PCK are represented within the context of the CoRe and specific examples of instructional strategies and representations, assessments, potential student difficulties, and curricular considerations are included. When reading the CoRe, it is important to read individual columns (e.g. Big Idea A) from the top to the bottom vertically. The columns extend beyond a single page.

Table 12: *Content representation for Emma*¹²

Content Representation (CoRe)			
Considerations	Big Idea A	Big Idea B	Big Idea C
	Plasma membranes are semi-permeable barriers.	Substances will diffuse along the concentration gradient.	During osmosis, water diffuses across a semipermeable membrane from high to low concentrations.
Identify the learning goals for students within this lesson.	Students should understand the nature of the cell membrane: <ul style="list-style-type: none"> • a lipid-rich structure. • surrounds the cell and creates a unique internal environment. • allows for the selective passage of materials into or out of the cell. 	Students should understand the concept of a concentration gradient: <ul style="list-style-type: none"> • relative concentrations of substances will determine the direction of osmosis or diffusion. • substances will diffuse from high to lower concentrations. • random molecular motion and collisions drive both diffusion and osmosis. 	Students should understand the function of a semipermeable membrane: <ul style="list-style-type: none"> • cell membrane maintains a unique environment within the cell • osmosis is the diffusion of water across a semipermeable membrane. • the direction of osmosis is results from a concentration gradient between cellular contents and the surrounding environment.

<p>Why is it important for students to know this content? [<i>Knowledge of curriculum</i>]</p>	<p>Plasma membranes are critical to life and life processes:</p> <ul style="list-style-type: none"> • maintaining the integrity of the cell. • photosynthesis and the generation of energy within the cell. • cellular respiration and the generation of energy to support cellular functions. <p>Plasma membranes maintain a unique environment within the cell:</p> <ul style="list-style-type: none"> • maintenance of homeostasis . 	<p>Concentration gradients:</p> <ul style="list-style-type: none"> • dictate the direction of osmosis and diffusion. • critical for understanding energy production (ATP) within the cell. • result in passive transport of materials through diffusion or osmosis into the cell. • substances diffuse from high to low concentrations. • random molecular motion drives diffusion. 	<p>Understanding of osmosis:</p> <ul style="list-style-type: none"> • supports students' understanding of the direction of water movement during osmosis. • supports understanding of relative concentrations of water on either side of a semipermeable membrane in terms of predicting direction of osmosis. • explains why water enters or leaves cells. • perception of osmosis and diffusion as overarching concepts in biology.
<p>Identify potential student difficulties and limitations associated with teaching this idea. [<i>Knowledge of students as learners</i>]</p>	<p>Cell membrane:</p> <ul style="list-style-type: none"> • structure of the membrane which results in semi-permeable nature. • the importance of the cell membrane in creating a unique environment within the cell. 	<p>Concept of concentration gradient:</p> <ul style="list-style-type: none"> • concentration of water can be determined from relative concentration of dissolved solid within a solution. 	<p>Direction of osmosis:</p> <ul style="list-style-type: none"> • determined by relative concentration of water within the cell and the surrounding environment. • osmosis references only diffusion of water through a cell membrane. • unique vocabulary important for associated with osmosis. <ul style="list-style-type: none"> ○ the terms: hypotonic, isotonic, and hypertonic can be confusing for students.
<p>Identify knowledge of students' thinking which influenced the teaching of this idea. [<i>Knowledge of students as learners</i>]</p>	<ul style="list-style-type: none"> • Importance of making connection between students' understanding of oil as hydrophobic (repels water) and cell membrane as a lipid-based structure. • Cell membrane is semipermeable. 	<ul style="list-style-type: none"> • Make connections between concepts and students prior knowledge and life experiences: <ul style="list-style-type: none"> ○ use food dye and water as model for diffusion. ○ concentration gradient in food dye and water is easy for students to see and understand. 	<ul style="list-style-type: none"> • Use whiteboard models of beakers containing corn syrup or distilled water with each containing an egg. • Ask students to draw arrows predicting direction of osmosis water in each diagram

<p>Teaching strategies and representations implemented and particular reasons for using these strategies to engage students with this idea. [<i>Knowledge of instructional strategies and representations</i>]</p>	<ul style="list-style-type: none"> • Review the structure of the plasma membrane - have students draw and label the structure in their notebooks. • Use a model of a cell with an internal membrane divided into two parts by a diagonal insert with small holes. <ul style="list-style-type: none"> ○ smaller white balls pass through diagonal membrane ○ larger red balls can not pass through the diagonal membrane. 	<p>Food Dye Diffusion</p> <ul style="list-style-type: none"> • Use food dye and water as a model for diffusion. <ul style="list-style-type: none"> • Place drops of food coloring into a beaker of cold water; students note changes occurring in model over time. <p>Decalcified Eggs</p> <ul style="list-style-type: none"> • Explain water movement observed in the decalcified eggs placed in distilled water or corn syrup environments. 	<p>Decalcified Egg Lab</p> <p>Students:</p> <ol style="list-style-type: none"> 1. Students make predictions about the direction of osmosis. 1. Mass eggs before placing eggs in corn syrup or distilled water. 2. Place decalcified eggs in distilled water or in corn syrup. 3. Make observations of decalcified eggs and note changes. 4. Use observations and data to test predictions. 5. Draw model to explain water movement. 6. Students share explanations and receive feedback from peers and teacher.
<p>Identify ways of ascertaining that students concepts taught. [<i>Knowledge of Assessment</i>]</p>	<p>Questioning students:</p> <ul style="list-style-type: none"> • ask students explain the importance semi-permeable membrane in cell life. 	<p>Assess accuracy of student explanations:</p> <ul style="list-style-type: none"> • students' explanations about direction of diffusion in food dye and water demonstration. • the direction of osmosis indicated with arrows in diagrams of decalcified eggs in beakers of corn syrup or distilled water. 	<p>Assess accuracy of student predictions to determine student comprehension:</p> <ul style="list-style-type: none"> • predictions of direction of diffusion in food dye and water demonstration • predictions of direction of osmosis in decalcified egg investigation.

Loughran, Berry, and Mulhall (2006) posit that “teaching requires considerably more than delivering subject content knowledge to students, and that student learning is considerably more than absorbing information for later accurate regurgitation” (p. 9). Thus, Emma’s PCK is an amalgamation of all components of PCK filtered by her orientation to science teaching, resulting in the transformation of content knowledge into a form understood by students.

¹²Note: Modified from *Understanding and developing science teachers’ pedagogical content knowledge*, by J. Loughran, A. Berry, and P. Mulhall, 2006, p. 28. Rotterdam: Sense Publishers.

Cathy's Case Profile

Cathy's Vignette: The Power of a Story

“Well, today we are going to make a story board” Cathy informs the class. “Does anyone know what a story board is?” she asks as she looks around the room at her students. There is a murmur of conversation in response to Cathy’s question.

“Hey, isn’t that what they do in Hollywood when they make movies?” a student asks.

Another student explains: “Yeah, they draw all of the action that will take place during a scene in the movie; it is kind of like a comic book.”

“Right” Cathy responds. “Well, today you guys are going to design a story board for Mr. Stink.”

The students look confused for a moment; a student in the back of the room asks: “So who is Mr. Stink?” Several students laugh as they wait for Cathy to provide a more detailed explanation.

“Okay, so you are in class and a kid walks in and he seems to be covered with this super powerful cologne. I mean, he really does smell; in fact, you could say he stinks” Cathy explains. “We will call this guy, Mr. Stink.”

“No joke, there was a guy like that in my dentist’s office last week” a student exclaims. “And he really did stink!”

“I am sure that we all have had experiences with Mr. Stink in one form or another” Cathy explains. “Today, we are going to turn the whiteboards into story boards,” Cathy tells her students. “I want you to divide the whiteboard into four panels and just like the comics and tell a story about Mr. Stink” she explains. “Your story about Mr.

Stink will address the molecules of that powerful cologne he is wearing and show what happens to those molecules of cologne as he enters the room at the beginning of class, during class, and then at the end of the class” Cathy explains.

“Okay, so you want us to tell the story in four steps” a student states.

“Do we use pictures and dialogue, like they do in the comics?” another student asks.

“Yes, that is right. I want you to start in panel number 1 with Mr. Stink, and you can use little dots to represent the molecules of cologne and show at least 20 cologne molecules. In each panel show what happens to those cologne molecules as Mr. Stink remains in the room” Cathy explains.

“Aren’t those molecules what everyone around Mr. Stink actually smells?” another student asks.

“Well, what do you think the dots represent?” Cathy responds. “In each panel, show what happens to the dots around Mr. Stink over time and then, on a separate piece of paper, your team will write a brief description of your story to share with the class.”

“So we work with our teams?” a student asks.

“Yes, you will!” Cathy responds. Cathy has implemented cooperative learning into her teaching and organizing students into pods; the pods are numbered and students within each team have specific responsibilities.

“Well, does everyone understand the assignment?” Cathy asked. The students nod quietly, waiting for further direction. “Okay, I would like each team to send your equipment manager to pick up the whiteboards, dry erase markers, and an eraser. You will have 15 minutes to complete the assignment” Cathy explains.

There is a flurry of activity as students move to pick up whiteboards, markers, and erasers for their respective teams. Gradually the students settle in to work and begin to focus on the assignment. While students are working, Cathy moves throughout the room and peers over students' shoulders. The students appear to be engaged in the activity, sitting with their heads together and working quietly. As student teams complete the assignment, Cathy invites three teams to share their ideas with the class. Cathy takes a seat waiting for the first group to begin their presentation.

Background and Context

Cathy is a veteran teacher with over 15 years of classroom experience teaching 10th grade General Biology at Fender High School. Currently, Cathy teaches 10th grade biology, dual credit biology, and genetics. Fender High School is the only high school within a small, rural, community. The 2000 Census identifies the population to be approximately 17,827 (U.S. Census, 2000). Fender High School has a population of 762 students with a minority student population of 12.1 percent, below the state average (DESE, 2008). The free/reduced lunch eligibility is 11.3 percent, significantly below the state average of 42.1 percent (DESE, 2008). The student to teacher ratio is 19/1, slightly above the state student to teacher ratio of 18/1 (DESE, 2008). The graduation rate at Fender High School is 79.7 percent and falls below the state average of 85.2 percent (DESE, 2008). Approximately 61.3 percent of Fender High School graduates attend a four-year or two-year college or university (DESE, 2008).

Cathy's classroom is divided into a traditional classroom area with student tables arranged in six pods consisting of two tables each, creating collaborative space for six teams of four students each. The other side of the classroom consists of a laboratory area

with six complete lab stations which include water, sink, electrical outlets, and gas jets. Cathy's room is part of a new addition to the school which was completed in 2007.

Cathy has implemented student driven research into her teaching through the Partnership for Research and Education with Plants (PREP); her students design their own research projects with wild type and mutant *Arabidopsis thaliana* seeds provided by plant science researchers from a research extensive university. Cathy has served as Fellow during two consecutive summers through an NSF program supporting the inclusion of teachers in formal laboratory research. As a Fellow, she worked in a plant research lab conducting research with wild type and mutant *Arabidopsis* and developed activities, investigations, and laboratory protocols for high school students.

Orientation to Science Teaching

I describe Cathy's orientation to science teaching within the following dimensions: (a) goals and purposes for science teaching; (b) interpretation of teacher role; (c) interpretation of student role; (d) ideal images of teaching; and (e) view of science as a discipline.

Goals and purposes of instruction. Cathy's overarching purpose is to actively engage students in learning and challenge them to think critically while constructing their knowledge of biological concepts. Cathy explained she initiated the osmosis and diffusion unit (the lesson prior to Day 1 of the observation) by engaging her students in an investigation which challenged them to identify the most absorbent layer of a disposable diaper. Her goal was to focus students on the characteristics of water and the diffusion of water into a diaper before addressing osmosis and diffusion within living

systems. She believed the activity stimulated student thinking about water in their daily lives. She explained the nature of the introductory lesson:

We did an introductory activity yesterday where we are just trying to get them into thinking about how things work. So we had them dissect a diaper to determine which layer of the diaper was most absorbent (pre-observation interview).

Cathy's purpose was to assess students' prior knowledge of water and diffusion to inform her next steps in the osmosis and diffusion unit. She explained: "The purpose today was to get them thinking about it so that when we talk about it in class they could put it all together" (stimulated recall interview, Day 2). Following the introductory investigation into water, Cathy's goal was to make connections between water and the cell. She explained: "So then we will begin talking about water and how important it is in the cells and that water balance in cells is very important" (pre-observation interview).

One of Cathy's goals in teaching biology is to make connections between biology and students' lives; she relied upon stories related to water loss and dehydration within the body. As a former coach, Cathy's experience with athlete performance, dehydration, and water intake provides fertile ground for stories, analogies, and metaphors related to the role of water in living systems. She explained her implementation of stories:

We talk about athletes and when they get to 2 percent or 3 percent dehydration, their performance begins to fail. We talk about football teams and volleyball teams and how they are always going to get a drink and how water is so important in maintaining body functions. (pre-observation interview)

Cathy noted she works with two other teachers in her department. Most of her planning is completed within the context of this group of teachers. She did not reference the teachers as a professional learning tea; however, she did note the goals and plans for teaching were developed through collaboration with colleagues. Cathy explained:

When you work with other people there is more flexibility involved. You may have a way you want to do it but it may not work for them, they may not have the experience to know. In some ways I never really thought about how flexible I try to be sometimes and how other times you cannot be. (pre-observation interview)

Cathy actively engages her students in learning through investigations in which students conduct explorations of content prior to explanations; she appeared to intuitively follow the sequence of the 5E instructional model (Bybee, 1997). Cathy relied upon investigations, analogies, and metaphors to make concepts clear to students. She challenged students to think critically and apply their knowledge to realistic problems and, by doing so, encouraged students to construct their knowledge of osmosis and diffusion. Cathy's planning and teaching clearly reflect her goals of actively engaging students in critical thinking and problem solving while constructing their knowledge of biology.

Perception of teacher role. Cathy explained that she perceives her role as a teacher to be continually shifting with the learning needs of her students. She posits the teacher's role may shift from a guide or facilitator for inquiry to a more structured, traditional role through which the teacher acts as a resource providing students with explanations and background information to enhance comprehension. Cathy noted students may have difficulty understanding content information from the textbook and considers other ways to make complex concepts more understandable for students. She noted, "I think that kids really do have problems understanding the molecular world. But hopefully using the models will help them get more of a visual perspective" (pre-observation interview). When acting as a resource, Cathy provides the information for her students often in the form of a PowerPoint lecture/discussion or worksheet. She explained:

This is one of those things that is hard for them to get it out of a book and read it on their own. So I am going to transfer the information to them by giving them some definitions and I also have a worksheet that we do (pre-observation interview).

Cathy stressed as a teacher, she must know students' strengths and weaknesses and rely upon feedback from students to determine next steps in the lesson. She noted, "I place a lot of what I do on feedback from the kids. If I see the kids are not understanding; I will make a change" (stimulated recall interview, Day 2). Cathy explained she uses her knowledge of her students to design learning opportunities tailored to students' needs and this sensitivity to students' learning needs is one of the most important aspects of the teacher role. Cathy explained:

You have to look at the capabilities of the kids and what their prior knowledge about the concepts is, what their past experiences are, how the kids are doing and then from that you have to decide how you can best introduce the activity or this knowledge. (stimulated recall interview, Day 2)

Challenging students to conduct investigations to find answers may be the most effective approach. If the content is challenging, students may need additional guidance and less of an inquiry approach. She explained:

The role changes; you can be a totally inquiry based teacher in which you are challenging students to find ways to answer a question. But I do not think that full inquiry works very well in a high school setting. Kids need more guidance in some areas and it changes with the chapter. . . . Something that is at a deep enough level or a high enough thinking level that the kids would have trouble with it; they would have trouble on their own trying to figure it out. So in that kind of chapter I am going to be more of the knowledge giver in some ways. (stimulated recall interview, Day 2)

Cathy identified motivating students as a key aspect of her role as a teacher. A former athletic coach, Cathy explained she relied on her coaching experiences for insight into student motivation and noted her teacher role often shifted into that of a coach. She explained, "Another role of the teacher is to be a coach. . . . So my thought was to

challenge the kids. . . . Students are a lot like athletes in some ways” (stimulated recall interview, Day 2). Cathy explained she strives to create a learning environment within her classroom in which students are engaged with content, motivated to learn, and challenged to think critically. She noted students must be actively engaged in learning.

Cathy explained:

I think that the kids have to take part in some way whether it is something simple like getting up and becoming part of a demonstration or body modeling or a cook book lab or maybe an inquiry lab but the kids have to be active participants. (stimulated recall interview, Day 2)

Cathy explained science has its own language and if students are to become fluent in science, they must speak the language. Thus, Cathy noted her teacher role includes reliance upon creativity in terms of creating games to support student learning of vocabulary terms and definitions. Students are responsible for generating flash cards for each chapter. Once the cards are completed, Cathy designs simple games to engage students in learning vocabulary. She explained:

So we do organelle flash cards with the organelle on one side and the function of the organelle on the other side. We talk about the organelles and what they do. We also play some games with the flash cards. We play one game called ‘Quiz, Quiz, Trade’. In this game, I will take one of my cards and partner with you and we quiz each other over the function of that one organelle that we picked out of our cards. . . . So this is just a little reinforcement. (pre-observation interview)

She perceives her role as a teacher is continually changing with the learning needs of her students and, therefore, demands flexibility and creativity. Cathy noted, “So I think that the role of the teacher varies with what you are teaching, how you want to teach it and who you are teaching it to” (stimulated recall interview, Day 2). Cathy described the role of the teacher to be a learner, a resource, a coach, and a facilitator. She explained a constant within her teacher role is creating a learning environment in her classroom in

which students feel safe, engaged as active participants in learning, motivated to ask questions and find answers, and challenged to think critically.

Perception of student role. Cathy explained that students play an integral role in their own learning. She believes that students cannot learn effectively as passive participants because in that role there is no real motivation to learn. She noted the students' role in the classroom shifts very much like the role of the teacher, in that students must be prepared to implement different learning strategies to develop a better understanding of concepts. She explained, "Sometimes the kids can sit and listen to me talk and sometimes they need to do that, but other times they should do some learning and digging on their own" (stimulated recall interview, Day 2). She believes students must learn how to read to gain insight and understanding. She explained, "They [students] need to learn how to read and pick out important information because the book is there to help them and it is just one resource for them to use (stimulated recall interview, Day 2).

Cathy reported in her classroom the students' role is that of an active learner and involves thinking critically, sharing ideas through collaboration with classmates, asking questions, and finding answers. She noted students must be prepared to meet learning challenges, however, Cathy also explained students' role may involve being an attentive listener and taking notes. The most important role of the student is to be prepared to learn.

Ideal images of teaching. Cathy's ideal images of teaching are clearly focused on students learning by doing. Because her classes are 90 minutes in length, she plans to engage her students with a variety of activities. Cathy explained, in an ideal lesson, she

would engage students in a discussion then shift gears and involve them in an activity that challenged them to collaborate with teammates and use their knowledge to solve problems. Cathy believes that students learn science most effectively by being actively engaged in learning and envisions her ideal lesson as one in which students are engaged in a variety of learning activities. She explained:

The kids have to see themselves as active participants in constructing their knowledge and I think because of the way that some teachers might teach that the kids are used to being passive receivers. (stimulated recall interview, Day 2)

Cathy believes learning is most effective when students are actively engaged and noted she strives to implement varied instructional strategies in her teaching. Her goal is to provide learning experiences which encourage students to think about the concept from different perspectives. She explained:

Well I try to plan as we go through the year. We may start out taking more notes but then we throw in the activities, the body modeling, the labs, cooperative activities. Knowing that kids have different ways of learning I try to present and implement different kinds of activities throughout the year. (stimulated recall interview, Day 2)

Cathy's ideal images of teaching include her image of the teacher as a life-long learner. She stresses the importance continual learning for teachers as well as their students. She demonstrated the importance of reflecting on her teaching and revising her plans to address student learning needs. Cathy also explained that she continually reviews student work to gain insight into student learning and use that feedback to redesign her lesson. Her ideal image of teaching is through inquiry-based investigations; however, she noted that time is often a major constraint for the inclusion of inquiry in the biology curriculum.

View of science as a discipline. The investigations Cathy implements into her teaching suggest she perceives science as a way of knowing which demands evidence. As a Research Fellow, she conducted research with *Arabidopsis thaliana* with plant science researchers at a research extensive university. Cathy believes her work as a Fellow has prepared her to implement student-driven research into her biology curriculum. Cathy's students design their own experiments with mutant and wild type *Arabidopsis thaliana* seeds provided by university researchers and share their conclusions and data with university researchers in an effort to provide additional insight into *Arabidopsis* gene function.

Cathy continually stresses the importance of evidence to her students by challenging them to make and test predictions during investigations. Her goal is to provide a learning environment in which students are encouraged to find answers to questions posed within laboratory exercises. She explained:

I think that students learn best when they construct their own knowledge and assimilate new knowledge into their knowledge base; they have got to do it you cannot just pour it into their heads. . . . they need some experience, you have to give them more guidance, but once you have done it you can ask them to think about it and design their own lab. (pre-observation interview)

Cathy explained she designs laboratory analysis questions challenging students to explain how they know claims in their conclusion are accurate. Therefore, she demands students support their explanations with evidence gathered during the investigation.

Cathy explained:

But to answer the questions they are going to have to begin to think "How am I supposed to know this?" If they ask me I might tell them to look back at their notebooks; so I might redirect them in that way. It is not my job to remind them of every little thing. They need to be independent thinkers and remember those things. (pre-observation interview)

She believes by demanding supporting evidence for students' claims she is teaching them to think critically and independently.

Cathy believes science must be taught in a way which underscores the importance of supporting evidence. She noted students do not automatically think about evidence to support their claims, but require guidance; however, once guidance is provided, her students are fully capable of designing their own laboratory investigations to find answers. A hallmark of Cathy's teaching is the requirement that students support claims, explanations, and conclusions with evidence gathered during their investigation.

Summary of Cathy's orientation to science teaching. Cathy explained her experiences as a tenth grade biology teacher, as an athletic coach, and as a member of professional learning team of biology teachers at her school informed her orientation to teaching science. Cathy's perceived her role to be a facilitator of students' learning and engaged students in explorations of phenomena through laboratory investigations and problem-solving. Cathy engaged students in generating explanations predicated upon students' observations from laboratory investigations. Figure 9 shows the sources which informed Cathy's orientation to science teaching.

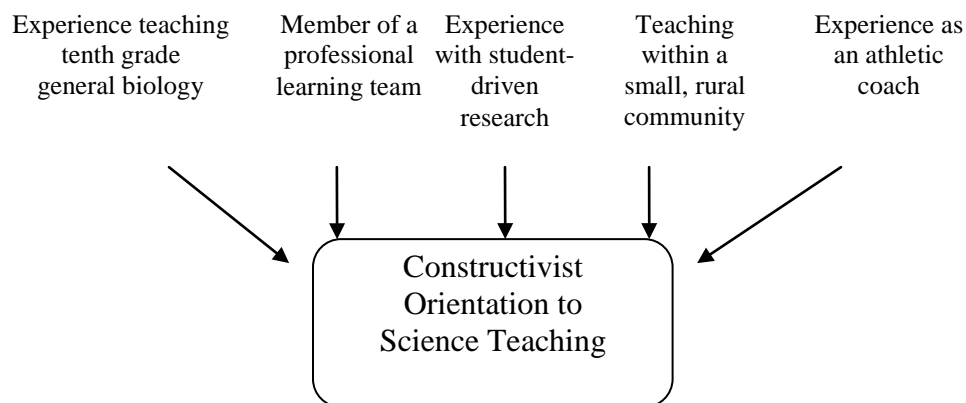


Figure 9: *Sources of Cathy's orientation to science teaching*

Cathy's experience with student-driven research has colored her view of science as a way of knowing that demands supporting evidence gathered through investigations. She understands the importance of evidence in science. Cathy challenges students to design investigations with *Arabidopsis thaliana* to make and test predictions, find answers to their questions, and to support their conclusions with evidence.

Based upon the following observations, I describe Cathy as having a constructivist orientation to science teaching. First, Cathy engaged students in an exploration of phenomena prior to introducing phenomena to students. On Day 1, she challenged students to create a storyboard explaining the diffusion of particles from Mr. Stink into the classroom. On Day 2, she challenged students to predict the direction of osmosis in dialysis tubing and potato slices and develop explanations based upon observations. Second, in each lesson, Cathy drew upon students' experiences to develop explanations. She used interactive lectures to draw out students' ideas, predictions, observations, and potential explanations. Interactive lectures are whole class discussions during which the teacher uses representations including: computer animations, diagrams, tables, charts, and pictures to make concepts understandable for students. This interaction between Cathy and her students supported students as they reflected upon their experiences to make sense of new ideas.

Lesson Plan

On Days 1 and 2, Cathy continued to build upon two investigations completed during an introduction into osmosis and diffusion during the previous lesson. The goal was to focus students on the nature of water and the relationship between temperature and

the rate of diffusion. Overviews of Cathy’s lesson plans for Days 1 and 2 are found in Tables 13 and 14.

Table 13. *Cathy’s lesson plan for Day 1*

Activity		Description
Day 1	Diffusion Demonstration	Engage Teacher: <ul style="list-style-type: none"> Challenges students to predict outcome of diffusion demonstration Uses drops of food dye in water as representation of diffusion
	Storyboard	Explore Teacher: <ul style="list-style-type: none"> Challenges students to develop cartoon storyboard to illustrate and explain diffusion (reveal misconceptions) Builds upon students’ prior knowledge of diffusion Students: <ul style="list-style-type: none"> Apply current understanding of diffusion to story board activity Explain story to class
	Interactive Lecture	Explain Teacher: <ul style="list-style-type: none"> Implements an interactive lecture to introduce concepts and terminology Representations of diffusion and osmosis [Internet animations and graphics] are implemented in interactive lecture Students: <ul style="list-style-type: none"> Respond to teacher questions
	Story Writing	Evaluate Teacher: <ul style="list-style-type: none"> Challenges students to identify factors that may influence diffusion Relates diffusion to molecular motion Students: <ul style="list-style-type: none"> Explain ideas Write a story to illustrate diffusion

During Day 1, the lesson began with a teacher demonstration focused on the diffusion of food dye particles in water. Cathy asks students to predict changes in a beaker of water after drops of food dye were added. She referenced a demonstration involving India ink and water completed with microscope slides during the previous lesson; she explained: “You could heat up the microscope slide and watch the ink move to see if the change in temperature makes a difference in the way in which the ink behaves. You just see those particles going crazy” (pre-observation interview). Her goal

with the India ink and food dye observations was to identify random molecular motion as the driving force for diffusion.

Cathy challenged student teams to develop a cartoon storyboard representation of Mr. Stink, a character wearing powerful cologne to illustrate diffusion. While students were working, Cathy moved around the room listening to students' ideas and responded to students' questions by posing new questions to guide their thinking. Student teams briefly shared their storyboards with the class and explained how and why diffusion occurred. Student practice consisted of a homework assignment in which they were asked to write their own story about diffusion. Cathy explained that she would read the stories to evaluate students' understanding of diffusion.

Cathy's plan for Day 2 of the observation began with an activity during which she engaged students with a story while slicing the potatoes in preparation for a laboratory investigation into osmosis and living tissues. The overview of the lesson plan for Day 2 of the observation is shown in Table 14.

Table 14. *Cathy's lesson plan for Day 2*

	Activity		Description
Day 2	Dialysis tubing investigation	Engage Explore	Teacher: • Facilitator for dialysis tubing investigation Students: • Set up dialysis tubing investigation • Make and test predictions of diffusion and osmosis
	Potato slice investigation	Explore Extrapolate	Teacher: • Facilitates potato slice investigation Students: • Make and test predictions for the direction of osmosis in potato slices
	Discussion	Explore	Teacher: • Uses questioning to reveal student comprehension • Require students to support conclusions with evidence Students: • Record results and collaborate with peers to explain observations • Identify supporting evidence for claims; share explanations with class

On Day 2 of the observation, students were challenged to predict the direction of osmosis and diffusion within dialysis tubing. Students filled dialysis tubing with a starch and glucose solution and placed the bag in a beaker containing iodine and distilled water. Next students were challenged to predict the direction of diffusion and osmosis before placing the dialysis tubing in the beaker.

After setting up the dialysis tubing investigation and predicting the direction of diffusion of glucose and iodine, students began Part 2 of the investigation and were challenged to predict changes to the potato slices prior to placing the potato slices in distilled water and a concentrated saline solution. At the close of the lesson, students observed the dialysis tubing and potato slices, developed data tables, recorded data from each part of the investigation, and used data from the investigation to test their pre-lab predictions. Student teams collaborated to respond to analysis questions and shared their explanations during a class discussion.

The lesson on Day 1 was designed to reveal student thinking about diffusion by engaging students with a storyboard activity and a teacher demonstration of diffusion incorporating food dye and water. On Day 2, students were engaged in two investigations into osmosis and diffusion. During the dialysis tubing investigation iodine and water diffused into the tubing and glucose diffused out of the tubing into the beaker solution. Starch molecules, too large to diffuse through the dialysis membrane, remained within the tubing and changed in color as iodine diffused into the dialysis tube. Changes in potato slices placed in distilled water or saline served as a model for osmosis. Students made and tested predictions for each investigation. Challenging students to make and test predictions was a common theme throughout Cathy's teaching on both Days 1 and 2.

The following sections address the other components of Cathy's topic-specific pedagogical content knowledge (PCK) for teaching osmosis and diffusion, including her knowledge of instructional strategies and representations, students as learners, assessment and curriculum.

Knowledge of Representations and Instructional Strategies

Cathy engaged students in a storyboard exercise to explain diffusion. She challenged student teams to create a story and sequential diagrams of explaining the diffusion of cologne in the air. Additional representations of diffusion and/or osmosis included drops of food dye placed in water to model diffusion, dialysis tubing as a representation of diffusion and osmosis within a cell, and potato slices as a representation of osmosis in living tissues.

Cathy embellished representations with story telling. She believes telling stories allows her to expand upon representations implemented into her instruction. She implemented a story about diffusion during Day 1 related to perfume brought home from Iraq by her brother. She explained that she used the story of the smelly perfume to provide students with a meaningful representation of diffusion. Cathy explained:

Then we start into talking diffusion and so I am going to talk to the kids and relay some stories about perfume. My brother bought me some perfume when he was in Abudabi during the first Gulf War. It is really stinky so I use it for demonstrations. (pre-observation interview)

She explained that through stories she is able to connect scientific concepts to real world experience for her students. She explained that biology is not a collection of facts but rather an understanding of how life works and, therefore, relevant for all students.

Cathy challenged her students to use story telling as a means of explaining diffusion. She used cooperative teams of four students each to design a storyboard

consisting of six panels to explain the diffusion of the scent of cologne from the character, Mr. Stink. She explained the purpose for the storyboard activity on Day 1 by stating:

Basically I am eliciting prior knowledge. Basically what happens to the smell and how is it that it gets to you? To see what these kids already know about it [diffusion], even if they have no formal prior knowledge they have experiential knowledge. They may have never thought that these stink molecules move. They may never have thought about stink molecules. So first we get them to draw it on the whiteboard and show the stink molecules in the air. (pre-observation interview)

She noted she planned to introduce the concept of diffusion through the storyboard activity prior to introducing vocabulary terms and planned for students to develop a definition for diffusion. Cathy planned to place drops of food dye into beakers of water as an example of diffusion. Her goal was to scaffold students' understanding of two key concepts: (1) random molecular motion as the driving force for diffusion and (2) diffusion occurs when substances move from high to low concentrations. She explained:

I will get some beakers and put them on the overhead and they can either see it from the side with the light coming up through the beaker or they can see it on the overhead. And so then I will ask the students to describe what is happening and to develop a definition for what is happening (pre-observation interview).

Cathy noted students may not identify the random motion of molecules from high to low concentrations as diffusion, however, they could explain what is occurring when cologne diffuses from Mr. Stink into the classroom. She explained: "I might not even use the term diffusion yet. But it is the idea of getting to what happens when the stinky person walks into the room; we can smell him eventually" (pre-observation interview).

Cathy emphasized the importance of making connections between vocabulary and students' prior knowledge and experience. She used an analogy between the term

hypertonic and a concentrated sugar solution; explaining if the solution were consumed would the individual could become hyper or hyper-active. She explained:

When we talk about tonicity I do not begin by giving a definition but I start out with a little skit or story. . . . I will find someone else who has been falling asleep in class. “Wow, listen you really need a pick me up and I will pour gobs and gobs of sugar into a third beaker and mix it up. So the kids will be grossed out and say “Yuck, who would want to drink that.” You know you do those extreme things and the kids will remember it more; you know that. So then I will talk about it and ask the students, “If George actually drank all of that sugar, what would it do to him?” They typically say that it would make him hyper. Now whether or not you agree that sugar makes kids hyper, here they have an idea that, wow there is a whole bunch of stuff in there [the solution], hyper, then they make that connection. (pre-observation interview)

Following the storyboard activity, Cathy engaged students in an interactive PowerPoint lecture and implemented animations taken from Internet sites to represent random molecular motion as the driving force for the diffusion. She explained:

Well, the animation shows the molecules of water and how they are moving and randomly. It is the same thing in the air. If the stink particles are out in the air then they are bumping into things. So I am trying to give the kids the idea that there are these particles in the air that take up space and these particles bump into each other and into things like stink particles in the air. (stimulated recall interview, Day 1)

Cathy made a connection between temperature and the rate of diffusion during Day 1 relying upon Internet animations to illustrate the relationship between changes in the rate of diffusion resulting from changes in the temperature of the system. She explained:

We might discuss kinetic energy and determine the amount of prior knowledge they have. We will look at energy and molecular motion. We might look at kinetic energy and temperature and the energy of molecules and what that means. We will talk about temperature and what temperature is actually measuring. We have one of the MoLo (Molecular Logic) animations to show this. (pre-observation interview)

Cathy noted the importance of instructional sequence and explained: “You can either talk about the content first, and then do a lab to confirm it, or you can do the lab first and then talk about it to help them understand what they saw” (stimulated recall interview, Day 2). She planned to scaffold students’ conceptual understanding of diffusion through the storyboard activity, the food dye diffusion demonstration, and the PowerPoint lecture prior to the dialysis tubing and potato slice investigations. She explained: “For this particular lab [dialysis tubing investigation], they need some background knowledge of diffusion and going from high to low concentrations and they have some knowledge but I do not know if they have put it together and understand diffusion across a membrane” (stimulated recall interview, Day 2).

On Day 2, Cathy planned to engage the students with two representations; each would be the focal point of laboratory investigations into diffusion and osmosis. Dialysis tubing containing a starch and glucose solution, was used to show diffusion and osmosis investigation within the context of a cell. The second representation, potato slices were used to represent osmosis in plant tissues and were placed in distilled water and a concentrated saline solution. Cathy challenged students to make and test predictions of outcomes for both investigations. She explained:

We usually stick to glucose and starch to start with and we usually stick with the dipstick test for glucose and the iodine test for starch. Those are pretty simple and pretty straight forward. But then when we do the extension lab we ask them to determine if water is moving in and how would they figure that out. That is where you leave it up to the kids and you basically tell them some things, like here is the glucose test and here is the starch test. (stimulated recall interview, Day 2)

She believed students constructed their understanding of osmosis and diffusion by making and testing predictions for the dialysis tubing and potato investigations.

Cathy planned to build upon students' understanding of osmosis with a demonstration and investigation during the following week. She planned to build upon students' understanding of osmosis in plant cells by placing a balloon, representing the central vacuole of a plant cell, in a box. Cathy noted the box would become rigid and resistant to pressure after inflating the balloon, illustrating changes in a plant cell after water entered the cell via osmosis. She explained:

I will use a balloon and a box to show them what happens when you blow up a balloon and place it in a box. So if the balloon represents the cytoplasm of a cell, I place the balloon in a box and blow the balloon up and then you can push on the box to demonstrate how with air in the balloon and with water in the cell, you have a crispy cell and with the air out of the balloon, you can easily mash the box in. so tomorrow I will do that demonstration. (stimulated recall interview, Day 2)

Cathy planned a follow-up investigation into osmosis in which red blood cells and red onion cells would be observed under a microscope when flooding a slide with a concentrated saline solution. She noted the cells would shrink due to water loss after exposure to a concentrated saline solution. Cathy explained:

There is another lab that we are going to do where we will plasmolyze cells [cause severe water loss by flooding cells with saline solution] under the microscope. We will use red onion cells and dog blood. We can watch the changes in the cells as they are exposed to hypertonic [highly concentrated] solutions. (pre-observation interview)

She noted a final connection between content and students' lives would be made at the close of the unit when students would make beef jerky in class. Cathy explained:

So the very last day of this chapter we talk about making beef jerky and we talk about putting the beef in salt water. So even though the beef is in water it is in salt water and it will lose water to the surrounding salt solution. (stimulated recall interview, Day 2)

On Day 1, Cathy challenged students to create their own representations of diffusion through an illustrated storyboard for Mr. Stink and his powerful cologne.

Following Mr. Stink, Cathy challenged students to explain diffusion observed within beakers of water into which drops of food dye had been placed. Cathy believed students made important connections between their storyboard explanation of Mr. Stink and the diffusion of food dye demonstration when students developed their own definition of diffusion. On Day 2, potato slices and dialysis tubing served as representations for tissues and cells for two investigations. Students applied their knowledge of diffusion and osmosis to make and test predictions of changes within the potato slices and dialysis tubing, building upon their knowledge of diffusion and osmosis.

Knowledge of Students' Understanding of Science

Cathy implemented the storyboard activity, on Day 1, as an introduction to the concept of diffusion and as a means of assessing students' prior knowledge and misconceptions. Through the creation of the storyboard, students collaborated on an explanation for the diffusion of cologne from Mr. Stink throughout the classroom and used their drawings to illustrate changes in the position of cologne particles around Mr. Stink. Cathy explained:

I kind of modeled Mr. Stink particles; I asked the one kid if he minded being Mr. Stink then I decided that he could be Mr. Smell Nice. If I am the particle I can begin next to you and where do I end up and some kids said that you moved away, someone else (another particle) could take your place. . . . I could have taken the MoLo and asked them if molecules have to be equally spaced or do they continuously move. (stimulated recall interview, Day 1)

Through the storyboard activity, Cathy was able to reveal a misconception held by students about diffusion. She noted one student team had arranged all of the particles of cologne along the edges of the final panel of their story board. The students explained their belief that the particles would move away from Mr. Stink into the surrounding classroom. However, Cathy was concerned students did not perceive random molecular

motion as the driving force for diffusion resulting in equilibrium of particles within Mr. Stink's surroundings rather than all particles simply moving away from Mr. Stink at a constant rate. She addressed this misconception with a story about blindfolded students moving randomly within a classroom and colliding with one another and gradually moving into less crowded regions of the room. By relating the story, Cathy's goal was to provide students with a concrete example of random molecular motion and collisions between molecules as the driving force for diffusion and osmosis.

Cathy believes students must be able to visualize abstract concepts; she included graphics and animations in the interactive PowerPoint lectures on Days 1 and 2. The animations were taken from the Molecular Logic (Concord Consortium, 2009) Internet site. Cathy's purpose in including the animations was twofold: first, she wanted to focus students' attention on random molecular motion as the driving force for diffusion and second, she planned to use the animations to illustrate changes in molecular motion brought about by changes in temperature. Cathy noted:

We will look at energy and molecular motion. We might look at kinetic energy and temperature and the energy of molecules and what that means. We will talk about temperature and what temperature is actually measuring. We have one of the MoLo (Molecular Logic) animations It is a computer animation. There are several different windows that you work through and one of them you have this box and you can place however many atoms you want in the box and the amount of available energy within the box. With a certain number, the movement may look random, but actually you can predict where the atoms will go. . . . It is not so much that the molecules think 'Oh it is too crowded here I have to go somewhere else.' When you have a high concentration of material in one place, the collisions occur at a greater rate resulting in the movement of particles from an area of higher concentration to areas of lower concentration. (pre-observation interview)

Cathy explained she knew of other strategies which could be implemented to illustrate the effect of kinetic energy on molecular motion. She explained, "You can take

a crystal under low or medium power on a microscope and just put a crystal of salt under there then focus the camera and then add water” (pre-observation interview). During Day 1, Cathy placed drops of food dye in beakers of water on an overhead projector to model diffusion for students and challenge students to predict changes in the water and food dye over time by drawing pictures of how they thought the mixture would change over time.

She noted:

I put twenty drops of food coloring in a beaker and then have them draw a picture of what the contents of the beaker would look like at specific times. So what would the beaker look like after ten minutes, or after twenty minutes and so on. Actually this is a test item it is just to show what would happen over time. (pre-observation interview)

Cathy reported that she used a different introduction with the previous class and placed drops of India ink in water on microscope slides as representations of diffusion. Students watched the ink diffuse into the water through microscopes and noted the ink moved more rapidly as the slide was warmed by the microscope light. She explained:

We could use the microscope to watch the ink blots. . . . You could heat up the microscope slide and watch the ink move to see if the change in temperature makes a difference in the way in which the ink behaves. You just see those particles going crazy. We will stop here to see what their background is in physical science in terms of solids, liquids, and gases and the distance between the particles and the amount of kinetic energy they have. (stimulated recall interview, Day 1)

In each representation, Cathy identified random motion influenced by heat energy as the force for diffusion. She noted the importance of implementing demonstrations which made connections between students’ knowledge and prior experience and content.

Concerned about students’ inability to visualize osmosis, Cathy explained she often used a balloon to represent a cell placed in hypotonic environment, such as distilled water and a hypertonic environment, such as a saline solution. She explained:

First we will take the balloon and I blow it up and then ask what will happen if you put it in a hypotonic solution [e.g., distilled water]. The kids say that water will enter the cell. So I blow and blow and water keeps on moving into the cell. I ask them what will happen if water keeps entering the cell so I keep on blowing into the balloon and finally the balloon blows up. But plasmolysis is the fun one because you have your balloon and you ask the kids if I put this in a hypertonic solution [e.g., a highly concentrated solution] what will happen and they tell you that water will leave the cell. So I let the balloon go and the air rushes out and makes the sound 'PPPPPPPT' I ask the kids to make that sound and they all go 'PPPPPPPPPT' and then I will ask them to say the word plasmolysis and then I will ask them to put the sound of the balloon together with the word plasmolysis so the kids then say PPPPPPLASMOLYSIS. (stimulated recall interview, Day 2)

Cathy believes lesson content should be sequenced to support students'

construction of knowledge. Initially, she began the unit by focusing students on water through an investigation into the relative water absorbance of various layers within a diaper. Next students generated a storyboard to explain the diffusion of cologne particles from Mr. Stink into the classroom followed by students' explanation of diffusion based up their observation of food dye in water. She explained that she did not include vocabulary terms until students had developed a definition of diffusion based upon the Mr. Stink storyboard, and the explanation of diffusion following an observation of food dye in water. Students were engaged in developing an explanation for diffusion on Day 1.

On Day 2, Cathy continued to build upon students' knowledge with investigations into osmosis involving potato slices and dialysis tubing. She introduced students to diffusion initially and expanded her focus to include osmosis and focus on students' ability to accurately predict the direction of osmosis. Cathy engages students with an investigation into potato slices and dialysis tubing. She plans to continue with a cytolysis lab following Day 2 to continue to build upon students' knowledge of osmosis and diffusion. She explained:

That is what we wanted to focus on today in the first part of the lab with the potato slices, and then the glucose and the starch in the second part of the lab. And then we will reinforce it again with the plasmolysis and cytolysis lab we will look at the cells under the microscope. This lab leaves some questions in their minds. It is OK to leave questions in kids' minds which might be a little confusing for them because they are still putting the pieces together. You cannot construct knowledge in just one day. You have to give them a little exposure here and then I can take them to the next step and talk more about water then do experiments which demonstrate for them what is happening to the water. (stimulated recall interview, Day 2)

Cathy emphasized the importance of engaging students with representations, demonstrations, and investigations to build upon students' comprehension of osmosis and diffusion. She explained that the effect is to divide content into smaller packets, allowing students to explore or consider one idea at a time. She explained her purpose for using iodine in the dialysis investigation on Day 2:

When they see that the dialysis tubing is turning purple. When they read their questions and think back to the demonstration I gave, students ask, "why is it turning purple?" Well iodine must be getting into the bag. So I ask them why is it turning purple and then ask them to think back. That is the fun part of the lab. They will be talking about that next time. (stimulated recall interview, Day 2)

Her goal is to challenge students to think about the direction of osmosis when the dialysis tubing and potato slices are placed in the distilled water and iodine solution. The iodine served as a marker, diffusing into the dialysis tubing with water and causing a color change within the tubing as it reacts with starch.

Cathy clearly understands that students are not blank slates, but bring their prior knowledge, experiences, and misconceptions into the classroom. She is aware of the importance of revealing and addressing student thinking, prior knowledge, and misconceptions to make learning more effective and meaningful for students. She demonstrated her knowledge of learners by initially accessing students' thinking about diffusion through the Mr. Stink storyboard activity, the India ink investigation, and the

food dye in water demonstration. She implemented laboratory investigations focused on osmosis and diffusion in which students were challenged to make and test predictions and explore the concepts while constructing their knowledge of osmosis and diffusion.

Knowledge of Assessment

Cathy noted the majority of assessments implemented in her lessons can be categorized as formative assessments. She explained that these assessments are very important because they provide a clear picture of students' prior knowledge and misconceptions as well as insight into students' learning within the context of a lesson. She explained that the storyboard activity on Day 1 was a pre-assessment designed to reveal what students knew about diffusion before introducing the concept. She explained how she uses the storyboard activity: "I use the storyboard with the stinky people. That is a pre-assessment to determine what students know and understand about diffusion before teaching the concept" (pre-observation interview). Cathy reported she routinely elicits student prior knowledge and experiences concerning lesson topics before teaching. Her purpose in revealing students' prior knowledge is to develop a clearer image of her students' ideas, understanding, and general knowledge about the concepts to be taught during the lesson. Cathy explained:

Basically I am eliciting prior knowledge. Basically what happens to the smell and how is it that it gets to them, and to see what these kids already know about it. Even if they have no formal prior knowledge they have experiential knowledge. (pre-observation interview)

Cathy explained that she relied upon student feedback during lessons to gain insight into student thinking and comprehension. She described her formative assessment of student understanding as resulting from observations of students' facial expressions and body language as well as her interactions with students. Cathy asked students to

consider what the molecules of cologne worn by Mr. Stink would look like, in terms of the distance between molecules indicated by the students. She asked students to illustrate the location of the molecules at different times to better indicate how students perceived diffusion occurring in the Mr. Stink storyboard. Cathy explained:

As I am watching students draw Mr. Stink, I am asking questions of the kids to make them to think more deeply. Like I had one group that from picture 1 and picture 2 all of the stink molecules were already spread out and I wanted it to be more gradually spreading out. So I asked them a question “What would it look like after one minute?” Since I wanted them to understand what was happening I wanted them to show the molecules more gradually spread out. I should have given them a time frame at first. But individually I can do that. So I asked “After one minute what would it look like and after 20 minutes what would it look like?” (stimulated recall interview, Day 1)

While students collaborated on the storyboard activity on Day 1 and during investigations on Day 2, Cathy moved through the classroom and continually questioned students to assess their understanding and to formulate a clearer picture of what students understood about diffusion and osmosis. She noted: “I felt that by the students talking to each other and by walking around and listening to the kids I noted that they all remembered concentration gradient, diffusion and equilibrium” (stimulated recall interview, Day 2). She explained that she evaluated the level of knowledge students held about diffusion and osmosis and took advantage of the opportunity to redirect students whose knowledge of diffusion may have been lacking. She explained:

So I am trying to evaluate what the kids are doing and determine if they are right and to redirect their thinking. So I am basically doing some assessment. For instance for Mr. Stink, what do they already know? Based upon what they knew I could see that the kids already knew diffusion but the kids were not using the word yet. So I am trying to evaluate what the kids are doing and I may try to redirect them if they are not where I want them to be or ask them some questions to see what they mean. (stimulated recall interview, Day 1)

On Day 2, students were challenged to write a story about diffusion in which vocabulary terms concentration gradient, diffusion, and kinetic energy were to be used. Her goal was to reveal student understanding of concepts related to diffusion and osmosis through their implementation of vocabulary terms.

Following the Mr. Stink activity, Cathy wanted students to apply their knowledge of diffusion of gases to diffusion of liquids. She asked students to predict changes when drops of food dye were added to tap water on an overhead projector. She explained, “I went with Mr. Stink so we did diffusion in a gaseous state. What would happen? Then I switched to you know, what would happen in a liquid and they were able to make some predictions” (stimulated recall interview, Day 1). Cathy planned to have students make and test predictions about the direction of osmosis and diffusion in the dialysis tubing and potato investigations. She planned to have students set up the dialysis investigation and answer questions to identify the highest concentration of each of the dissolved solids (starch, iodine, and glucose) and predict the direction of osmosis and diffusion of dissolved solids. Cathy explained, “Some of the questions I am asking, some of them are very basic like, Where is there a high concentration of starch, in the bag or in the beaker?” (pre-observation interview).

After completing the dialysis tubing investigation, she planned to have students redesign the investigation to change the direction of water movement through osmosis or the direction of diffusion of glucose and iodine. She wanted students to apply their knowledge of diffusion and osmosis to the design of a new investigation in which the direction of diffusion and osmosis would be different from the original. She believed this

challenge would reveal the conceptual understanding of diffusion and osmosis held by the students. Cathy explained:

What I will typically do is have them redo the dialysis tubing part of the lab but I will say OK, that time we made glucose move in. How could you set up the same sort of deal and have water move in or water move out or glucose move in or glucose move out and measure it. And then have the teams come up with the set up for the lab. The teams would draw a picture of their lab. What will they put in their beaker and what will they put in the hot dog (dialysis tubing), what do they expect to happen and how will they measure it and explain how it happens? (pre-observation interview)

Cathy embedded formative assessments, such as the storyboard activity, to assess students' prior knowledge and identify misconceptions before introducing the concept of diffusion to students. She explained her rationale was to reveal students' prior knowledge and misconceptions about diffusion and consider adaptations to make learning experiences more effective. When students collaborated on the storyboard activity about Mr. Stink, Cathy moved through the classroom as students worked asking questions and redirecting students' thinking when necessary. She also implemented formative assessments in the form of writing assignments through which students were directed to write a short story about diffusion in which specific terms were to be used. Cathy explained the formative assessments provided valuable insight into student thinking and informed her next steps during the lesson.

Knowledge of Curriculum

Cathy noted the importance of vertical alignment within the science curriculum; on Day 1 she implemented the storyboard activity and diffusion demonstration to reveal students' prior knowledge of atoms and molecules as well as molecular motion and noted the concept of kinetic energy is included within the ninth grade physical science

curriculum. She stressed the importance of students' conceptual understanding of kinetic energy as the driving force for diffusion and osmosis. She explained:

So basically the idea was so kids understand what atoms and molecules are, that is what it boils down to. They should have had this in their background with physical science. Like you could tell when they were talking about kinetic energy and solids, liquids, and gases and the distance apart or between the atoms and molecules. They knew that solids, liquids, and gases had different amounts of motion and different amounts of distance apart. (stimulated recall interview, Day 1)

Cathy sequenced the introduction of the concepts of diffusion and osmosis to support students' construction of knowledge. Students were initially engaged in an exploration of phenomena prior to generating an explanation. Students shared observations of the phenomena during investigations to develop explanations during interactive lectures during which Cathy supported students in the construction of their knowledge with computer animations and analogies. Hence, explanations of phenomena were derived through students' explanations supported by recorded data from and observations made during investigations.

Cathy noted the biology textbook is a basis for curriculum design at her high school. She believes students benefit from explorations of osmosis and diffusion. Cathy noted her plan to engage students in an exploration of osmosis with the potato and dialysis tubing investigations before providing an explanation of osmosis. She explained: "We have not even talked about osmosis even though they saw it today. So what we will have to do is we will have to try in the next lesson to tie it all together for them" (stimulated recall interview, Day 2). Cathy believed the sequence of learning opportunities on Days 1 and 2 supported students' construction of knowledge of diffusion and osmosis. Osmosis was introduced through an exploration with the the dialysis tubing

investigation and reinforced with the potato investigation. During the lesson following Day 2, Cathy planned to make connections between students' understanding of osmosis and their lives by observing microscopic changes in red blood cells and red onion cell following exposure to a concentrated saline solution. She explained:

That is what we wanted to focus on today in the first part of the lab with the potato slices, and then the glucose and the starch in the second part of the lab. And then we will reinforce it again with the plasmolysis and cytolysis lab we will look at the cells [red onion cells] under the microscope. (stimulated recall interview, Day 2)

Cathy believes the vertical alignment of the curriculum is critical because students must possess specific knowledge to be successful in future courses within the district curriculum. She explained her reliance upon multiple resources such as the textbook, textbook support materials, Internet resources, and colleagues when designing instruction. She noted the importance of flexibility in making adjustments when time constraints interfered with curricular planning and noted reliance upon her teaching experience when designing curriculum.

Cathy's PCK for Teaching Diffusion and Osmosis

Evidence of Cathy's knowledge of subject matter, representations, instructional strategies, learners, assessment and curriculum are shown in Magnusson et al. (1999) model for PCK which has been modified to reflect Cathy's PCK for teaching osmosis and diffusion.

The modified Magnusson et al. (1999) model of Cathy's PCK has been designed to identify and provide support for Cathy's constructivist orientation to science teaching. The influence of Cathy's orientation on the components of her PCK is indicated by the solid arrows leading from her orientation to the PCK components. Cathy's constructivist

orientation to science teaching is best represented by her approach to teaching science; she engaged students with explorations prior to generating explanations supported with evidence taken from students' observations. Cathy's PCK for teaching diffusion and osmosis is shown in Figure 10.

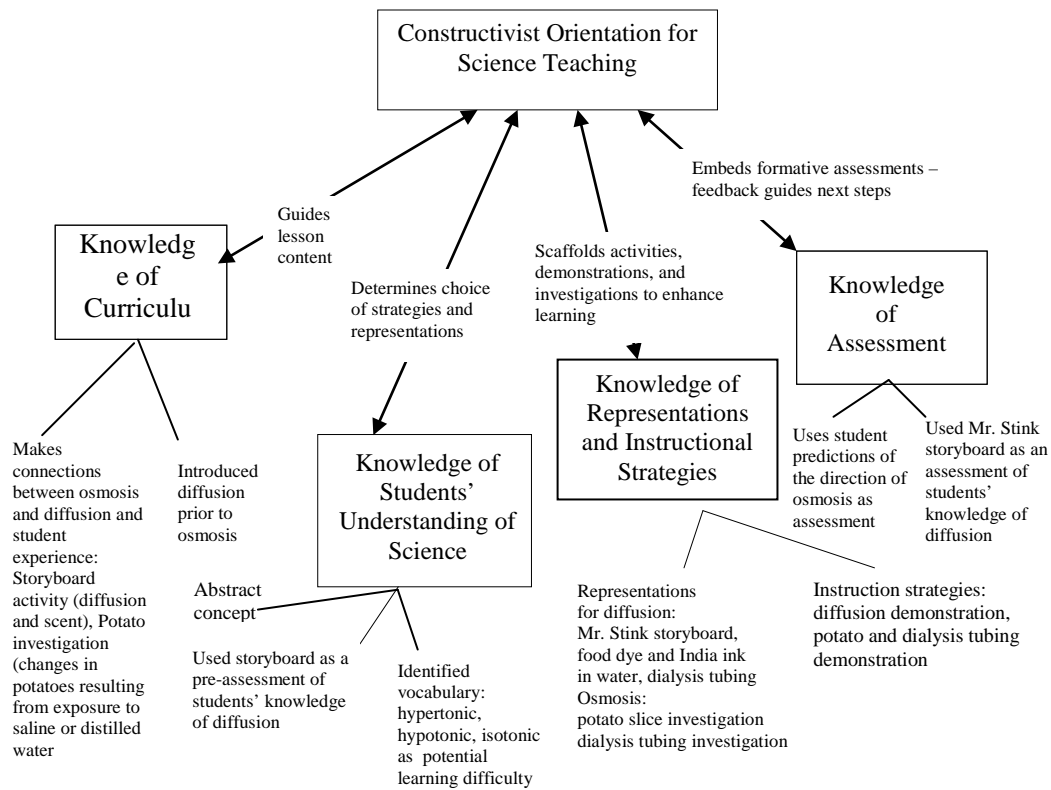


Figure 10¹⁰: Cathy's topic-specific PCK

On Day 1, students collaborated to create their own definition for diffusion when Cathy implemented the storyboard activity to reveal students' thinking about diffusion

¹⁰Note: Modified from Nature, sources and development of pedagogical content knowledge for science teaching by S. Magnusson, J. Krajcik, and H. Borko, (p. 99). In J. Gess-Newsome and N. Lederman (Eds.) Examining Pedagogical Content Knowledge. Boston, MA: Kluwer Academic Publishers

and the food dye diffusion demonstration to reinforce the notion of random molecular motion resulting in the movement of materials from high to lower concentrations.

Thus, she focused students thinking on molecular motion and relative concentrations as they developed their own explanation for diffusion before formally being introduced to the concept. On Day 2, Cathy reinforced students' knowledge of diffusion and introduced the concept of osmosis through the potato and dialysis tubing investigations. In each investigation, students were asked to apply their knowledge of diffusion and expand their thinking to include osmosis when making and test predictions; she noted that the nature of students' predictions provided insight into their comprehension of random molecular motion as the driving force for diffusion and osmosis. The integration of the components of her PCK is shown in Figure 11.

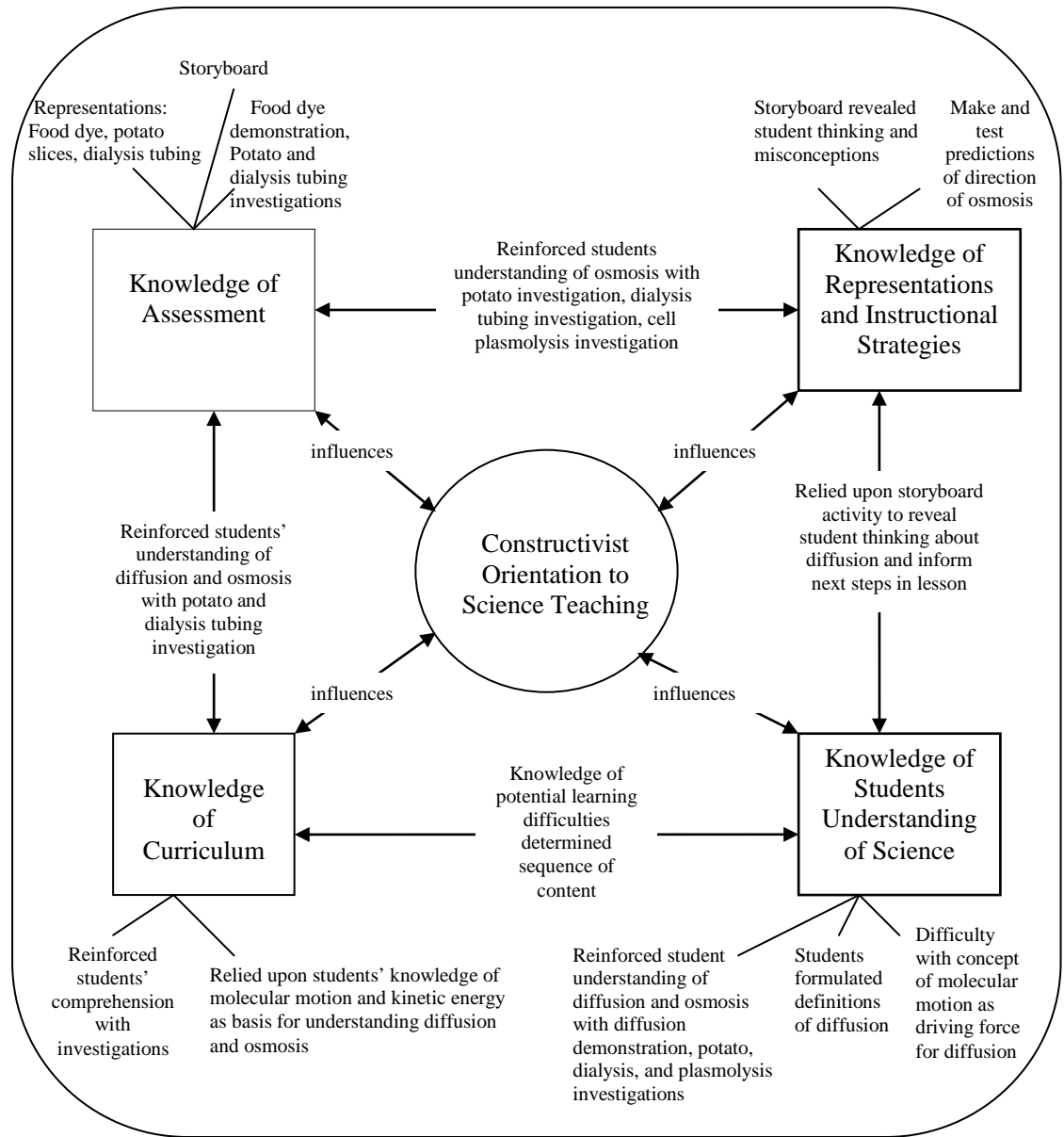


Figure 11: *Integration of Cathy's topic-specific PCK*

This model represents the integration of the components of Cathy's PCK to create a form of teacher knowledge specific for teaching diffusion and osmosis. There are four important features to note within this representation. First, Cathy's orientation forms the centerpiece of the model, indicating the importance of her orientation as a lens through which other components are interpreted and integrated. Second, two components are

within bolded boxes: knowledge of students' understanding of science and knowledge of representations and instructional strategies. These components are critical to Cathy's teaching; she relied upon her knowledge of students as learners and potential learning difficulties to design representations and instructional strategies implemented into her lessons. Hence, bolded boxes and arrows indicate these two components of teacher knowledge were highly integrated and determined how assessments and curricular decisions were made during the lessons. Third, connecting arrows indicate relationships between the Cathy's orientation for science teaching and other PCK components and also relationships between the knowledge components of her PCK. Bolded arrows between components indicate Cathy relied heavily upon her knowledge of students, representations, and instructional strategies to create the most effective learning opportunities for teaching osmosis and diffusion. She relied upon her knowledge of assessment to design formative assessments to reveal prior knowledge and gauge conceptual understanding. The sequence of her lessons derived from her curricular knowledge, in that she implemented an implicit 5E instructional model into her teaching. Fourth, connecting statements between components provide insight into Cathy's rationale for her integration of knowledge for teaching diffusion and osmosis.

Cathy drew heavily upon her knowledge of students as learners when designing and teaching lessons; she believed students were capable of conducting inquiry based investigations and modified lessons to compensate for potential learning difficulties. The representations, instructional strategies, and assessments implemented in the lessons were reflective of Cathy's goals for student learning and her knowledge of potential learning difficulties. She embedded formative assessments into her lessons, using students'

predictions and explanations to inform next steps in her lessons. Cathy’s knowledge of curriculum and curricular resources informed her implementation of the potato and dialysis tubing investigations as well as the implicit 5E instructional model. Cathy integrated all PCK components when teaching diffusion and osmosis.

Content Representation

In Table 15, a Content Representation (CoRe) illustrates Cathy’s knowledge for teaching osmosis and diffusion. The components of PCK are represented within the context of the CoRe and specific examples of instructional strategies and representations, assessments, potential student difficulties, and curricular considerations are include within the CoRe. When reading the CoRe, it is important to read individual columns (e.g., Big Idea A) from the top to the bottom vertically. The columns extend beyond a single page

Table 15. *Content representation for Cathy*

Content Representation (CoRe)			
Considerations	Big Idea A	Big Idea B	Big Idea C
	Diffusion occurs in gases, liquids, and solids and is driven by molecular motion	The concentration gradient determines the direction of diffusion/osmosis and heat energy will influence the rate of diffusion	Osmosis is the diffusion of water through a semi-permeable membrane following the concentration gradient
Identify the learning goals for students within this lesson.	Students will be able to: <ul style="list-style-type: none"> • explain diffusion within gases and liquids. • relate direction of diffusion to concentration gradients. • explain the influence of heat energy on the rate of diffusion. 	Students will be able to: <ul style="list-style-type: none"> • accurately predict the direction of diffusion or osmosis. • explain the concept of concentration gradient. • random molecular motion is the driving force for both diffusion and osmosis. 	Students will be able to: <ul style="list-style-type: none"> • accurately describe the structure of the cell membrane the semi-permeable nature of the membrane. • understand the direction of osmosis is determined by the relative concentration of water in two solutions separated by a semipermeable membrane.

<p>Why is it important for students to know this content? <i>[Knowledge of curriculum]</i></p>	<p>Key content knowledge:</p> <ul style="list-style-type: none"> • diffusion and osmosis are core concepts in biology. • diffusion is driven by molecular motion and the kinetic energy within the system. 	<p>Ability to predict direction of diffusion and osmosis:</p> <ul style="list-style-type: none"> • predictions of diffusion based upon concentration gradient. • predictions of direction of osmosis based upon relative concentrations of water in two solutions separated by a semi-permeable membrane. 	<p>Understanding of the function and structure of the cell membrane:</p> <ul style="list-style-type: none"> • all cells have a semi-permeable cell membrane. • only certain substances can pass through a semipermeable membrane.
<p>Identify potential student difficulties and limitations associated with teaching this idea. <i>[Knowledge of students as learners]</i></p>	<p>Diffusion:</p> <ul style="list-style-type: none"> • perception of random molecular motion as driving force. • difficulty with vocabulary terms and definitions: <ul style="list-style-type: none"> ○ hypotonic, hypertonic, isotonic, and concentration gradient 	<p>Osmosis and diffusion in relation to the concentration gradient:</p> <ul style="list-style-type: none"> • diffusion follows a concentration gradient - particles move from greater to lesser concentrations • osmosis follows the concentration gradient of water – water molecules move from greater to lesser concentrations 	<p>Factors explaining the direction of osmosis:</p> <ul style="list-style-type: none"> • direction and rate of osmosis is influenced by relative concentrations of water within the cell and within the environment. • random molecular motion as the driving force for osmosis. • vocabulary associated with osmosis is unique and challenging for students.
<p>Teaching strategies and representations implemented and particular reasons for using these strategies to engage students with this idea. <i>[Knowledge of instructional strategies and representations]</i></p>	<ul style="list-style-type: none"> • Use analogies to explain relate random molecular motion to diffusion. • Story-board activity to challenge students to create a model for diffusion. • Demonstrate diffusion with food dye in water. • Use computer animations to illustrate diffusion. • Students write a story in which they explain diffusion implementing three terms related to diffusion: concentration gradient, molecular motion, and kinetic energy. 	<ul style="list-style-type: none"> • Use a representation of a cell (dialysis tubing) as the focus of an investigation into the direction of diffusion (iodine and glucose) and osmosis. • Use potato slices as representations of plant tissues to investigate the direction of osmosis. • Students make and test predictions for the direction of diffusion and osmosis in each investigation. • Support claims and explanations with evidence (observations) from the investigations. 	<ul style="list-style-type: none"> • Students make and test predictions of changes in the starch and glucose solution within dialysis tubing placed in a beaker containing distilled water and iodine. • Students explain the increase in the volume and color change within dialysis tubing before and after placing the bag in the beaker solution. • Students explain diffusion of glucose into the beaker solution from dialysis tubing solution. • Introduce concepts prior to vocabulary terms later.

Identify ways of ascertaining that students understand the concepts taught. <i>[Knowledge of Assessment]</i>	<ul style="list-style-type: none"> • Assess student prior knowledge of diffusion through the storyboard activity. • Assess accuracy of student story about diffusion in which concentration gradient, molecular motion, and kinetic energy. • Assess students' prior knowledge through accuracy of predictions. 	<ul style="list-style-type: none"> • Assess accuracy of student predictions of the direction of osmosis before students begin the potato investigation. • Assess students' answers to the potato lab analysis questions. • Use predictions during investigation to assess students' conceptual knowledge. 	<ul style="list-style-type: none"> • Assess accuracy of student predictions for the direction of osmosis and diffusion prior to dialysis tubing investigation as a pre-assessment and during investigation to reveal students' conceptual knowledge of osmosis. • Use questioning during the dialysis tubing investigation to evaluate student comprehension of osmosis and diffusion.
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The CoRe (Loughran et al. (2004) documents the topic-specific PCK Cathy holds for teaching diffusion and osmosis. Cathy's knowledge and practice are aligned with the big ideas or objectives of her lessons.

¹³Note: Modified from *Understanding and developing science teachers' pedagogical content knowledge*, by J. Loughran, A. Berry, and P. Mulhall, 2006, p. 28. Rotterdam: Sense Publishers.

Janis's Case Profile

Janis's Vignette: Effective Analogies

“Okay, so we have been talking about cellular organelles over the past few days,” said Janis. “Yesterday, we looked at *Elodea* leaf cells and saw how the cells responded when we flooded the leaves with distilled water” she noted. “What changes did you see in the cells of the *Elodea* leaf when you put distilled water on the leaf? Janis asked her students.

“Well, when we added distilled water, the central vacuole inside the cells seemed to get bigger” a student responds.

“Yeah, the cellular organelles got squeezed together as the vacuole got bigger,” another student explained.

“Why do you think the central vacuole got bigger? What was happening when distilled water was placed on the *Elodea* leaf?” Janis asks. She directs the students, “Take the next two minutes to talk to your partner and generate an explanation you can support with your observations,” Janis asks. There is a muffled buzz in the classroom while students collaborate.

“Okay guys, your time is up. Who would like to share their ideas with the class?” Janis moves between the lab tables when two students suddenly raise their hands. “All right, James and Adam tell us what you think” Janis responds.

“We think the distilled water went into the cell and then went into the central vacuole” Adam responds. “Yeah, the central vacuole is where plant cells store water; and when water moved into the vacuole, it got bigger and squished the cytoplasm and organelles up against the inside of the cell membrane” James adds.

“What about everyone else, do you agree with this explanation” Janis asks as she looks around the room.

“We think Adam and James are right, the water moved into the cell” a student responds referencing herself and her lab partner.

“How did this happen? How did water get into or out of the *Elodea* cells?” Janis asks.

“Like, it went through the cell membrane right?” a student in the back of the room asks.

“Okay Julie, I think you are on to something there,” Janis replied. “What did we say makes up the cell membrane?” Janis asks the students.

“I know,” a student in the back of the room states raising her hand. “It’s made up of fats or um, lipids, right?”

“Good, lipids would make a good membrane, but I thought lipids were not soluble in water, don’t you put wax on your car to protect the paint?” Janis asks.

“Hey, stuff has got to be able to get into and out of the cell, so the membranes have to let some stuff pass through to get in or out,” a student responds.

“Okay, but do you think there is anything that cannot move through the membrane?” Janis asks the students.

“Well duh, not everything can enter or leave the cell. I mean the cell has to keep certain things in that it needs for life and it has to keep other things out, so not everything can pass through the membrane,” the student responds.

“Hey, this is a semipermeable membrane, we talked about this at the end of class yesterday” a student notes.

“Good!” Janis states. “So the membrane will allow only some substances to pass through it? Josh, are compounds other than lipids associated with cell membranes?” Janis asks.

Josh blushed and stammered “Well my notes say that its phospholipids, proteins and carbohydrates. I think you called them glycoproteins and lipoproteins, right, Mrs. B?”

“Good job, Josh,” Janis states. “Carbohydrates attached to proteins within the cell membrane are called glycoproteins and carbohydrates attached to the lipids in the membrane are called glycolipids,” Janis stopped and looked out over the class before asking her next question. “So, tell me why are glycoproteins and lipoproteins important for your cells?” She asked. Students pondered the question but no one responded.

“Well, yesterday, we said that proteins could form channels, kind of like doors in the membrane,” a student responds.

“If we think about water moving through protein channels into the cell, we have a way for water to enter the cell. This is good. But why does water enter the cell? What is driving this movement?” Janis asks as she looks over the class. Students sit silently, not sure of how to respond to Janis’ question.

“Okay, I want you to create this picture in your mind. Imagine this room is filled with students who are blindfolded and cannot see anything and the students are in constant motion moving around and colliding with one another,” Janis explains.

“Now imagine that a door is opened between my room and Ms. C’s room next door. What do you think will happen to the students over time?” Janis asks.

“Well, I think that some of the students would find the opening by chance, you know, just sort of bump into it,” a student responds.

“Yeah, some of the students would move into Ms. C’s room,” another student adds.

“So you are telling me that students would randomly move from a crowded space into a less crowded space. Is that right?” Janis asks.

“Well, yeah, that makes sense to us,” a student responds and several students seated nearby nod in agreement.

“So what do you think is driving the movement of water into the *Elodea* cells?” Janis asks.

“Like, could it be the same thing. I mean, the *Elodea* leaves were in distilled water and that is like pure water with nothing else in it, right? A student asks.

“Well, I think you are on to something, the blindfolded students in our little scenario are like water molecules in that they cannot see all movement is random and collisions are occurring everywhere,” Janis explains.

“So, you mean that the water molecules are going from more crowded to less crowded conditions, kind of like the students we talked about?” a student asks.

“Yes, I want you to think about this scenario as you continue with the *Elodea* investigation and predict what you think will happen when the leaves are exposed to a saline solution,” Janis explains. The students nod in agreement.

Janis directs students’ attention to the microscopes and the lesson continues as students continue to observe the *Elodea* cells as the leaves are flooded with a concentrated saline solution. Janis plans to continue the discussion and elicit students’

explanations for the driving forces osmosis following their observation of *Elodea* leaf cells.

Background and Context:

Janis is a veteran biology teacher. She has taught high school biology for 15 years at Silver Springs High School. The Silver Springs School District is within an affluent community with a population of approximately 70,000. The average class size within the high school is 16 students, which is below the state average of 18 and approximately 70 percent of Silver Springs High School graduates go on to attend a four year university or college (DESE, 2008).

In 2008, Janis earned National Board Certification in Adolescent and Young Adult Science. She served as the Science Department Chairperson for the past five years, guiding the development of biology curriculum and common assessments.

Orientation to Science Teaching

I describe Janis' orientation to science teaching in terms of: goals and purposes for science teaching, perception of teacher role, perception of student role, ideal images of teaching, and view of science as a discipline.

Goals and purposes of instruction. Janis' overarching purpose of instruction is to engage students in the construction of their knowledge of biology through investigations into biological concepts. She explained:

You know I have a tremendous respect for their ability to learn and for their enthusiasm for learning. But I do not think it is recognized and appreciated. There is too much of here is the assignment, sit down and do it and we will have a test on it. This does not allow students the opportunity to explore and engage their minds and to actually construct knowledge. I am a little bit of a constructivist in terms that I think that students should construct their own knowledge. (pre-observation interview)

She believes students construct their knowledge of science by making connections between concepts and developing a perception of biological concepts as interconnected knowledge explaining the nature of life rather than as disparate clusters of facts about plants, animals, and the environment. Her purpose is to scaffold student learning so that students create a schema or framework in which to organize and integrate new knowledge. Janis explained:

No piece of knowledge exists independent of other pieces of knowledge; you have to be able to fit new knowledge into what you already know. And you have to have that framework but it has to be a piece, it just can not exist independently, you have got to make connections. So if I am going to talk about cell membranes, which we will do today, and if I am going to talk about how that cell membrane works, then I cannot talk about that without also talking about phospholipid molecules. (Stimulated recall, Day 1)

Janis' believes making connections between students' current knowledge of biology and new concepts is critical for effective learning and an important aspect of her instruction: "The more connections we make, the better we understand" (stimulated recall, Day 2). She noted, "If you teach them biology as disparate pieces of information, it is kind of like, okay I finished the cell cycle now lets go on to the next thing and I do not have to think about this any more (stimulated recall interview, Day 2). She continually spirals back to previous lessons with the goal of building connections between concepts, lessons, and units. She explained:

If you keep bringing it into things like cancer and mutation and evolution and when you do those things go back and say Hey do you remember when we talked about the structure of DNA? Hey do you remember when we talked about this? Then they start to make connections and things start to make more sense. (stimulated recall interview, Day 2)

Janis' goal in teaching involves providing students with opportunities to construct their knowledge of biology by making connections between concepts and actual

experiences. She explains: “Everything is connected in biology; nothing stands by itself” (stimulated recall interview, Day 2). She identified a goal for teaching biology is to assist students with the construction of a schema in which to articulate and coordinate new knowledge. Janis believes knowledge cannot exist as separate bits but must be placed within a larger context to make sense to students. Thus, her purpose in teaching is to assist her students in making connections and constructing an accurate picture conception of life and how life works.

Perception of teacher role. Janis identified her teacher role as continually shifting throughout the lesson. She made important connections between investigations, activities, and students’ knowledge and experience. Janis noted a key aspect of her role as a teacher is to identify and implement representations to make abstract concepts understandable for students. Janis noted the power of animations, videos, and graphics as tools for enhancing students’ comprehension. She explained:

Long ago, I went to putting in pictures and animations, whatever I could in the notes. These are places where I try to translate the words on the paper into something that they [students] can really grab a hold of better. . . . I just think that students need something to work with so that they can translate something that to most of them is very conceptual and put it into action. (pre-observation interview)

Janis believed animations provide concrete images of abstract structures within the cell. Hence, animations supported students’ construction of knowledge of cellular structures and functions. She explained: “The more times that you can have the students think about and process information, the better they will be at understanding and internalizing that information” (stimulated recall interview, Day 1).

She implemented Wisconsin Fast Plants into her curriculum to stimulate students’ thinking about plants as organisms and the requirements for life from germination

through growth and reproduction. Students make and record observations of Fast Plant growth and reproduction as the plants progress from seed to seed in approximately 45 days. She explained: “Well, we grow Fast Plants and there are a few reasons why we do that; one reason is that they get into the habit of making observations” (stimulated recall interview, Day 1). Students will pollinate the plants and gather seeds to be germinated and grown for a genetics investigation during the spring semester when students will plant the seeds and observe the F2 generation of Fast Plant offspring. She explained:

So the Fast Plants are this great big longitudinal thing that has lots and lots of applications, it is observational, it is genetic, and it is plant physiology and anatomy. . . . it provides an ongoing project in which the students have ownership. (stimulated recall interview, Day 1)

Janis related osmosis and diffusion to Fast Plants by focusing on the mechanism of water movement through plants and plant wilting in a water deficient environment. She consistently asked students to reflect on their experiences with the Fast Plants when discussing the role of water in living things. By observing the plants over time, students had living examples of many of the concepts studied in class and as a result, Janis believed her students developed a deeper understanding of content.

Janis implemented potato slices as representatives of plant tissues and designed the potato slice investigation as an opportunity for students to explore cell membranes and osmosis. She explained: “You know this is part of the reason you do a lab. It is to solidify. These labs are not experimental labs. These labs are to help them [students] take what they know and really apply it” (stimulated recall interview, Day 1).

Janis believes her role as a teacher is never static but shifts with the needs of the students; she varies instructional strategies in her lessons. She explained: “I will try to come at it from three or four different ways to help students” (stimulated recall interview,

Day 2). Janis believes that an important aspect of her role as a teacher is to be aware of teachable moments. She understands that something which occurs unexpectedly may be a windfall in terms of helping students understand and process new knowledge. She explained: “there are also unexpected things that happen, you know, we may have really strange things turn up in the slides and this is an opportunity to learn and observe” (stimulated recall interview, Day 1). Janis made a connection between student observation of cells within *Elodea* leaves on Day 1 and a creek lab designed as an introduction to one-celled organisms, completed earlier in the semester. When a student found Protists on his *Elodea* leaf; Janis’ response was to stop the lab and invite all of the students to observe the slide. She referenced student observations of Protists during the creek lab to provide a frame of reference for students’ observation of Protists on the *Elodea* leaf. Janis explained: “Of course, all of the kids were crowding around because they wanted to see the Protists moving around all over the place. That is not something that I anticipated but it is a great learning experience” (stimulated recall interview, Day 1).

Janis also collaborates with other biology teachers within her high school, her school district, and professional organizations. Through professional interactions with school and district Professional Learning Teams (PLT), Janis reflects upon her teaching practice and considers her goals in terms of students learning. Janis explained she collaborates with her PLT to develop learning goals, biology curriculum, and common assessments to clarify perceptions of teacher’s and students’ roles in teaching and learning. She noted:

Discussions with other teachers, I do a lot of NSTA conferences, I have a good community of biology teachers here [in her school and school district] who share

ideas. I have a wider community of teachers within the NSTA list serve and then classes and professional development opportunities. (pre-observation interview)

Janis is a participant in a university program, Partnership for Research and Education with Plants (PREP). She noted she works with plant research scientists to implement student driven research into her Advanced Placement Biology Curriculum. Janis explained she uses PREP as a model for student-driven research with Wisconsin Fast Plants in her tenth grade biology classes. She challenges students to make observations and record observations as the plants grow, pollinate the plants, and collect the seeds. During the spring semester, her students will plant the seeds and compare the characteristics of the offspring to the parents during an investigation into genetic inheritance in plants.

Janis is highly reflective about her teaching practice and noted her experience with earning National Board Certification strongly supported reflection on her practice in terms of students' learning. Clearly, Janis perceives the role of the teacher as one which is continually shifting to meet the learning needs of her students. She builds opportunities for students to explore, construct, and apply knowledge through laboratory investigations. She noted the value of PowerPoint lectures and discussions with connections to Internet animations and graphics to provide students with greater insight into diffusion and osmosis. She implemented representations for cell membranes, osmosis, and diffusion including: potato slices, cells observed within the *Elodea* leaves, Wisconsin Fast Plants, graphics, animations, analogies, and diagrams. Janis' goal is to actively engage students in learning and implement multiple opportunities to make connections between lessons, units, and real-world situations.

Perception of student role. Janis' perception of the student role is that students must take responsibility for their learning. She believes that students will not be able to progress with their education and meaningful learning without assuming personal responsibility as a learner. She explained:

Students have to take responsibility for their education, they really do. . . . I have this very strong belief that you have to take responsibility. These kids cannot progress to junior college or college unless they are going to take responsibility for their own work. (stimulated recall interview, Day 2)

Janis is always considering new ways to engage her students in learning. She noted as she gained teaching experience, she placed increasing importance on investigations. She encourages students to find ways to apply their understanding of biological concepts by challenging them to “translate something that is very conceptual and put it into action” (pre-observation interview).

Janis perceives her role and the role of her students as influencing one another. She is consistently searching for ways to challenge her students to apply their knowledge of biological concepts to real-world issues through laboratory investigations. By taking this approach, she is placing more responsibility on her students to think deeply about their knowledge of biological concepts as they apply their ideas to develop explanations for laboratory investigations.

Ideal images of teaching. Janis explained she perceives her role as teacher to be continually changing as she adjusts her practice to meet the needs of her students as learners. She noted, “I think that the role of the teacher shifts” (stimulated recall interview, Day 2). At times, she perceives herself to be the teller, providing her students with information through interactive lectures and discussions. She explained: “I think that there are times when the teacher is the deliverer of information” (stimulated recall

interview, Day 2). Janis described her ideal image of teaching by describing herself “as someone who excites curiosity so that students would be interested enough to pursue and investigate on their own and that happens” (stimulated recall interview, Day 2). She described golden teaching moments as times when she stimulates curiosity among her students and she and her students are able to learn together by posing questions and investigating ways to find answers. She explained:

My preferred mode would be that I am up here as a colleague and we are learning together, that is the ideal. Sometimes that happens but it does not often happen, but those are the golden moments. Those are the moments when a student will ask me a question and we will Google it or they will go home and investigate it. Those are great moments for teachers and for students. The students become the teacher in those moments and you always learn better as the teacher. (stimulated recall, Day 2)

Janis perceives herself to be a facilitator and in some ways a colleague, actively engaged in learning with her students. She explained that engaging students as partners in learning is what she strives to accomplish in her teaching; her goal and ideal image of teaching. She explained that when students perceive themselves to be responsible for finding the answers to questions they have posed, learning is much more effective. By viewing herself as a fellow learner, Janis encourages students to take greater responsibility for their own learning, search for evidence, and develop relevant explanations and applications for their knowledge.

View of science as a discipline. Janis explained that she views of science as a way of knowing which demands evidence and implements a Wisconsin Fast Plants investigation during the first semester to engage students with growing and observing plants throughout their life cycle. Janis identified two reasons for including Fast Plants in

her biology curriculum. First, students are able to conduct a long term investigation into plant growth. She explained:

They are supposed to be making observations about how fast the plants grow, what they look like, what do the first leaves look like, what do the second set of leaves look like. Because they are looking at something that is growing, because they planted them, they are really invested in the plants. (stimulated recall interview, Day 1)

Second, Fast Plants serve as a model for investigating plant anatomy and physiology, life cycles, pollination, and seed production. Janis noted:

They are observing plant anatomy, they do not see the germination, but they are observing plant growth, they are looking independently at stems and leaves. So when we talk about plant organs later on, it is real easy to talk about roots, stems, and leaves. They will be pollinating them, so when we do that we will talk about the difference between pollination and fertilization and they will harvest the seeds. As we do genetics and we start talking about predicting the outcome of crosses we will go straight to our fast plants. They will do an exercise or two where they work through Punnett squares and investigate data statistically to determine phenotypic ratios. (stimulated recall interview, Day 1)

Janis emphasizes the tentative nature of scientific knowledge by engaging students in investigations designed to find answers to questions about life. Students are expected to conduct investigations, gather and organize their data, draw conclusions from their observations and support conclusions with evidence taken from their data.

Summary of Janis' orientation to science teaching. Janis noted her experience with teaching tenth grade biology, serving as a member of a professional development team, conducting laboratory investigations with Wisconsin Fast Plants, and achieving National Board Certification informed her goals and purpose for teaching biology as well as her perceptions of her role as a teacher and the role of students as learners. She noted the importance of conducting explorations of phenomena, making connections between biological concepts and students' prior knowledge and experience, and generating

explanations predicated upon students' observations and ideas. By making connections between content and students' prior knowledge and experience, Janis believes she is providing opportunities for students to construct their knowledge of biology and create a schema to make sense of new knowledge. Hence, she believed students' learning is based upon understanding biology by connecting concepts and building a framework explaining how living systems function. Figure 12 shows the sources which influenced Janis' orientation to science teaching.

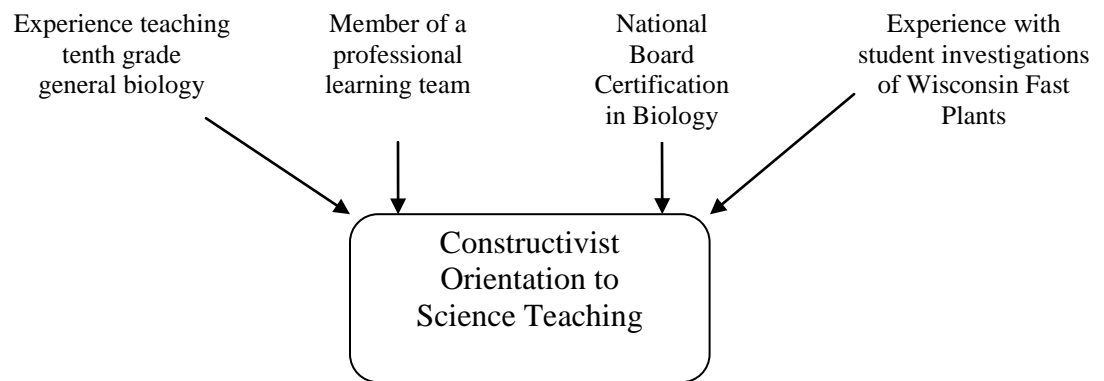


Figure 12: *Sources of Janis' orientation to science teaching*

I describe Janis' orientation to science teaching as constructivist as a result of the following observations. First, Janis implemented an implicit 5E instructional sequence and engaged students with explorations of concepts prior to explanations. Second, Janis perceives science as a means of answering questions through investigations and requires students to support claims with evidence. Janis noted she designed and conducted investigations with her students when questions arose in class. Third, Janis challenged students to make and test predictions during investigations and reflect upon their experiences with the concept to support their conclusions. Janis made connections between osmosis and students' prior knowledge and experiences to make lesson content

relevant for students. Hence, her instruction incorporated a constructivist approach to teaching and learning.

Lesson Plan

Day 1 of the observation began with students observing plant and animal cells. An overview of Janis' Day 1 lesson plan is shown in Table 16.

Table 16. *Janis' lesson plan for Day 1*

Activity		Description	
Day 1	Observation of <i>Elodea</i> leaves following exposure to distilled water and saline	Engage	Teacher: <ul style="list-style-type: none"> • Challenges students to predict changes in <i>Elodea</i> leaf cells • Observes students' work during <i>Elodea</i> investigation and redirects students' thinking with questions Students: <ul style="list-style-type: none"> • Predict changes in <i>Elodea</i> resulting from exposure to distilled water or saline solution • Observe aquatic plant, <i>Elodea</i>, leaves placed in distilled water or a saline solution • Test predictions
	PowerPoint lecture and discussion	Explain	Teacher: <ul style="list-style-type: none"> • Conducts lecture/discussion focused on cell membrane structure • Implements representations of cell membranes, osmosis, and diffusion Students: <ul style="list-style-type: none"> • Explain predictions and support claims with observations
	Discussion of <i>Elodea</i> leaf observation	Explain	Students: <ul style="list-style-type: none"> • Explain their observations of <i>Elodea</i> leaves; note change in vacuole size and the environment in which the leaf or cheek cell was placed

Leaves of the aquatic plant, *Elodea*, served as representations of plant cells.

Students were challenged to note changes in cells within *Elodea* leaves after exposure to distilled water or a saline solution. Students were instructed to note differences in the size of the central vacuole and the condition of chloroplasts within *Elodea* leaf cells upon exposure to each environment. Janis moved through the classroom to observe students' work and question students about their observations and explanations. Students

participated in an interactive PowerPoint lecture following observations of *Elodea* during which the structure and function of the cell membrane were discussed.

On Day 2, students continued to investigate osmosis and diffusion through a potato stick investigation. An overview of Janis' Day 2 lesson is shown in Table 17.

Table 17. *Janis' lesson plan for Day 2*

	Activity		Description
Day 2	Investigation focused on osmosis in potato slices	Engage Explore	Students: <ul style="list-style-type: none"> • Students set up a potato slice investigation in which potato slices are observed before placing the sticks in distilled water or a concentrated saline solution • Predict changes in potato slices
	PowerPoint lecture and discussion	Explain	Teacher: <ul style="list-style-type: none"> • Conducts class discussion on membrane permeability and diffusion along a concentration gradient (from high to lower concentrations) Students: <ul style="list-style-type: none"> • Provide rationale for predictions
	Students observe and explain changes in potato slices	Explain	Students: <ul style="list-style-type: none"> • Potato slices are observed and students test predictions • Develop explanations for changes observed in potato sticks Teacher: <ul style="list-style-type: none"> • Challenges students to support claims with evidence

Students were challenged to make and test predictions of changes within potato slices placed in two different environments: distilled water and a saline solution. Students collaborated with lab partners to develop predictions and determine how their predictions would be tested. Next, students placed potato slices in beakers containing distilled water or saline. After setting up the investigation, students engaged in an interactive lecture discussion when students shared their predictions with the class and focused on the diffusion of water during osmosis.

I describe the components of Janis' pedagogical content knowledge including knowledge of instructional strategies and representations, students understanding of

science, assessment and science curriculum specific for teaching osmosis and diffusion in the following section of the case study.

Knowledge of Representations and Instructional Strategies

Janis implemented representations of living cells and tissues to enhance students' comprehension of osmosis and diffusion. On Day 1, Janis engaged students with a microscopic investigation of cells within *Elodea* leaves. *Elodea* cells were the focal point of an investigation into the direction of osmosis following exposure to environments of distilled water or a concentrated saline solution. Janis challenged students to make and test predictions about the direction of osmosis before exposing leaves to each environment. Janis explained, "They will start out by observing cells *Elodea* leaves and then put the leaves into a hypertonic solution and then into a hypotonic solution and watch them respond to those environments" (stimulated recall interview, Day 2). By observing living cells in different environments, students were able to observe osmosis and relate the direction of osmosis to the relative concentrations of solutes within the cell and the environment. During the investigations, Janis emphasized vocabulary: hypertonic, hypotonic, isotonic, and concentration gradient to her students and made connections between the terms and changes within the plant cells. She explained:

They will remember what happens to cells in a hypertonic [highly saturated solute] environment because they have held it in their hands and they have seen and thought about what happened to it better than they will remember a picture that I put up on the board of a cell with Xs and Os on it. So I guess that I am hoping to establish some kind of a framework into which they can fit the information that comes on the following day about diffusion and osmosis. Even if the only thing that we do is raise questions, I am OK with that, because that produces some kind of disequilibrium into which some of those answers will filter. (pre-observation interview)

Janis believes that even though students “learn best by doing. . . . you have to have a lecture component” (pre-observation interview). Janis believes the knowledge students attain through interactive lectures allows for an exchange of ideas and provides a framework for students to make sense of the new knowledge gained through investigations and activities. She explained:

I cannot talk about the nature of how the cell membrane works without talking hydrophobic and hydrophilic. We have already covered that and they already know why those molecules are hydrophobic and hydrophilic. So if I am going to say that water cannot get through the cell membrane because of this hydrophobic layer in the membrane. . . . Then they have made that connection and they are reinforcing previous knowledge and they are taking that previous instruction which may not have had context earlier and they are placing it in a meaningful context. They are placing it in context that becomes more meaningful. (stimulated recall interview, Day 1)

Janis explained students would apply their understanding of cell membrane structure to explain the diffusion of water through cell membranes during the microscopic observations of *Elodea* cells on Day 1. She noted the importance of spiraling back to access content information covered earlier in the course to increase relevance for students. She explained:

So hopefully we will go back, of course, with the cell membrane we will go back over and over again. I am just trying to get them to access prior knowledge and put it to use rather than allow that knowledge to be compartmentalized. (stimulated recall interview, Day 1)

On Day 2, Janis engaged students with a potato slice investigation as a discrepant event in which students placed potato slice, a representation for plant tissue, in distilled water or a concentrated saline solution. Students were challenged to make and test predictions of potential changes in the potato slices before the slices were placed in distilled water or saline. Janis encouraged students to reflect upon their observations of

osmosis at the cellular level during the *Elodea* investigation to help them predict changes in plant tissues during the potato slice investigation. Janis explained:

I just think that students need something to work with so that they can translate something that to most of them is very conceptual and put it into action. The potato slice is something that we have done for years and years as part of our diffusion and osmosis lab. But it was more of a cook book lab; here is what you do and here is what you should find, now answer these questions about them. I am trying to use that differently. I am trying to use it more as a discrepant event. This is an experiment. We will see what happens. (pre-observation interview)

Janis emphasized the importance of students' observations. She explained. "If I can get them to start to pull out ideas about something going in and something going out. These potato slices that we put into the salt solution look different than those potato slices that we put into the distilled water" (pre-observation interview). Janis believes that by challenging students to explain their observations during investigations, she is helping them to make connections between investigations and their conceptual understanding of osmosis.

Technology was an important aspect of Janis' teaching. She relied upon computer graphics and animations to provide students with models of osmosis and diffusion. Animations from Molecular Logic (Concord Consortium, 2009) website provided an animation of diffusion and osmosis. Janis explained that she relied upon websites and computer software programs to access animated images making abstract concepts like diffusion and osmosis understandable for students. She explained:

We have gotten hold of some really great chemistry computer software programs which has some really good illustrations of diffusion. I have also pulled a couple off of the Internet for diffusion and osmosis. I think it really helps them to see random collisions. (stimulated recall interview, Day 2)

Janis implemented a graphic of a protein channel molecule to help students understand how water actually enters the cell. She emphasized that the function of the protein

channel as a portal for water to enter the cell and, in doing so, provided students with an accurate explanation of how water molecules actually enter the cell. Janis explained:

I have a picture of an aquaporin, a protein data base picture. It is beautiful and you can see the channel right through it. So what I will probably do is to say, “OK, you remember when we talked about how water gets into and out of the cell, it is through an aquaporin.” (stimulated recall interview, Day 2)

Janis described herself as a ‘story teller’ and often used analogies in the form of a story to make a point and provide students with concrete examples of abstract ideas. To explain random molecular motion as the driving force for diffusion, she related a story about 400 blindfolded students moving randomly in classroom. After presenting the scenario, Janis drew upon student predictions and explanations to identify random motion as the driving force for diffusion. She explained:

If I put 400 blindfolded students wondering around in the room and cut a hole in the wall is it likely that some of them will go over to Ms. C’s room or will all of them stay in here? We kind of set that up as diffusion is due to the random motion of dumb, stupid, blind molecules type of thing. (stimulated recall interview, Day 2)

Janis provided insight into her implementation of instructional strategies by identifying the importance of students making connections between scientific concepts and their prior knowledge and experience. She explained that the Wisconsin Fast Plants were an excellent way to make connections between the role of water in living systems and plants. She explained:

We certainly made the connection between the Wisconsin Fast Plants and the water vacuoles because we came in on Monday morning and a couple of the kids had not given their plants sufficient water so they came back to wilted plants. So we started the day out by talking about why those plants are wilted and what is different. (stimulated recall interview, Day 2)

When Janis explained the structure of the cell membrane to her students, she used an analogy of hollow plastic balls floating on the surface of a tub of water. This analogy

created an image of the cell membrane as a structure made up of discrete lipid molecules forming a barrier between the inside and outside of the cell. Janis explained that by creating this image, she was able to make a connection between the cell membrane as a fluid barrier between the interior of the cell and the environment. She explained:

Like we talked about the bath tub today, that is the fluid mosaic model for cell membranes. . . . If I drop the balls on the surface of the water in the bathtub, what happens do they stay in a pile, the answer is no they spread out. (stimulated recall interview, Day 2)

Janis engaged students with microscopic and macroscopic representations which served as the focus for investigations into osmosis in plant cells and tissues. She challenged students to make and test predictions for each investigation. By challenging students to make and test predictions, Janis was able to reveal students' thinking as well as challenge students to apply their understanding of cell membranes, diffusion, and osmosis to new scenarios. Janis believed that, as a result, students would develop a clearer understanding of how and why water would enter and leave cells; thus, enhancing their understanding of osmosis and diffusion. She selected representations carefully and implemented those most likely to resonate with her students.

Knowledge of Students' Understanding of Science

Janis designed her lessons to engage students with representations of cells, tissues, and osmosis; she implemented laboratory investigations for students to explore osmosis, construct their knowledge passive movement of materials into or out of the cell. She noted many of her students "do not understand what is driving the movement of molecules during osmosis and diffusion" (stimulated recall interview, Day 2). She reported that models and analogies provide representations of abstract concepts which are understandable for students. Janis explained effective representations are critical for

student learning and support students' construction of a framework in which to integrate new knowledge. Janis implemented strategies including the observation of cells in *Elodea* leaves and potato sticks to engage students with concrete examples of osmosis within living tissues. In each case, students predicted changes then tested their predictions by observing osmosis on cellular and tissue levels in *Elodea* cells and potato tissues. Janis explained:

These potato sticks that we put into the salt solution look different than those potato sticks that we put into the distilled water. Why do they look different? Hopefully I can get them to establish some kind of a schema within which they can actually fit the facts of diffusion and osmosis. (stimulated recall interview, Day 2)

Janis is also well aware of misconceptions that students may hold about osmosis and diffusion. She identified the belief that salt is able to absorb water as a common misconception held by her students. On Day 2, Janis revealed this misconception when she challenged students to predict changes in potato slices placed in a saline solution or distilled water prior to the investigation. When several students explained that salt had the ability to absorb water and would actually absorb water from cells within the potato slices, she challenged them to try adding water to a pile of salt at home and report their observations on the following day. She explained:

They were really stuck on that misconception that salt sucks up water. I actually have four or five students who told me that if I took a pile of salt and put water on top of it, the water would disappear because the salt would suck it up. (stimulated recall interview, Day 2)

Janis planned to discuss students' perception of salt absorbing water on the following day and noted she would implement a demonstration with potassium polyacrylate, the absorbent polymer used in baby diapers, and compare the absorption of water by the

polymer to the interaction between salt and water to dispel the notion that salt is able to absorb water.

Janis believes she is a constructivist and designs learning experience to support and encourage students to construct their own knowledge. Her perception is that interactive lectures are beneficial, but have limitations as teaching tools and believes that students must be actively engaged in learning and processing new knowledge. On Day 1, Janis initially engaged students by investigating changes within cells of *Elodea* leaves when exposed to solutions of varying concentrations of dissolved solid. This simple investigation bypassed abstract notions of cell membranes, osmosis, and diffusion and allowed students to directly observe water movement in living cells within different environments. She explained:

We will put *Elodea* cells into different solutions, they will start out by observing and then put them into a hypertonic environment and then into a hypotonic environment and watch the *Elodea* cells respond to those environments. (stimulated recall interview, Day 1)

Janis noted students' process new knowledge by integrating new ideas and explanations into an existing schema. Hence, Janis made connections between students' observations and vocabulary terms. She knows that students are most effectively engaged with content when they can relate new knowledge to their lives and past experiences. She explained:

I can say you remember what happened to the potato slice in the salt water. They have an experience that they can refer back to. I am setting up a real life example for them to refer to I guess as much as anything else. I find that tremendously helpful. I can draw pictures forever on the board, but they will remember it if they hold that potato stick in their hands and if they have to think about what happened. They will remember what happens to cells in a hypertonic environment because they have held it in their hands and they have seen and thought about what happened to it better than they will remember a picture that I put up on the board of a cell with Xs and Os on it. So I guess that I am hoping to establish some kind of a framework into which they can fit the information that comes on the following day about diffusion and osmosis. (pre-observation interview)

Janis explained that she draws upon content taught earlier in the year to help students make connections between concepts, reinforce prior knowledge, and place new understanding into a more meaningful context. She introduced the concept of osmosis to students, engaging them with investigations into osmosis and asking them to make predictions about the direction of osmosis prior to introducing and explaining vocabulary terms. Janis planned to first engage with the concept to create a format in which to place new knowledge, such as vocabulary terms. Janis explained:

Hopefully I can get them to establish some kind of a schema within which they can actually fit the facts of diffusion and osmosis. Also allows what I think is an opportunity to ferret out glaring misconceptions that might be out there. Because there are always those and hopefully because we will be talking about membranes in the middle of this, we just talked about central vacuoles, hopefully we can pull the information from the organelles and talk about membranes together with organelles. Hopefully they will mesh together better. (pre-observation interview)

This comment underscores Janis' knowledge of learners. She noted when students fit new knowledge into existing knowledge, their understanding becomes more relevant and meaningful underscoring the importance of scaffolding student knowledge and encouraging students to construct a framework for their existing knowledge and as a format for new knowledge.

Janis noted students must make connections between their knowledge and experiences and new concepts. She notes this is critical in categorizing and integrating new knowledge into their ideas about the natural world. She noted students have diverse learning preferences and, to be effective, lessons must include a variety of representations (e.g., models, analogies, metaphors, examples) and engage students in investigations that challenge them to apply their knowledge to make and test predictions and use their evidence to provide explanations. Janis focuses on making connections between lesson

content and student prior knowledge and experience; her representations are designed to engage students with realistic examples, analogies, and metaphors common to students' lives.

Knowledge of Assessment

Janis embedded formative assessments into her teaching. She relies upon pre-assessments, such as student predictions. Prior to beginning the potato slice investigation, students predicted changes in the potato slices placed in distilled water or a saline solution. The predictions provided insight into students' thinking and prior knowledge of diffusion and osmosis. Janis believed student feedback provided important insight and informed her next steps in the lesson. She explained:

The potato slices, the idea for that is to actually fulfill a lot of purposes. One is pre-assessment, I am trying to get them to think and predict what will happen next. If I can get them to start to pull out ideas about something is going in and something is going out. These potato sticks that we put into the salt solution look different than those potato slices that we put into the distilled water. Why do they look different? (pre-observation interview)

Janis implemented stories into her teaching and asked students to predict what they believed would happen next in the story to reveal students' conceptual knowledge of diffusion and osmosis. She explained:

I get to be a story teller and talk about blind, stupid, molecules. I use the 3 blind mice on the PowerPoint to represent molecules. I will talk to them about that and we will set up the scenario. I am going to set it up so the whole discussion is focused on what will happen next and why do you think that will happen. So I am going to do that and you could call it a formative assessment. (pre-observation interview)

Janis developed a second scenario in which she described 400 blindfolded students moving randomly in her classroom. She explained

This is not just me telling a story it is me setting up a scenario and then asking them to predict what is going to happen next. I do not tell them and I do not know

of a good one for diffusion and osmosis other than the 400 blindfolded kids in the room. I ask the kids with all of the blindfolded students in the room, many of them will be up against the wall, what if I cut a hole in the wall. I will ask them what will happen next and then they will tell me that some of the students will go through that opening into the other room. Will they know that there is a hole in the wall? The kids will say no, some of them will just bump into the opening and go through it. (stimulated recall interview, Day 2)

She began asking students what guided the movement of the blindfolded students.

Students responded by stating the movement was random and not guided by sight. In the scenario, the blindfolded students represented the random movement of molecules colliding with one another and diffusing from higher to lower concentrations. She explained:

Of course, I am setting up an analogy of how molecules move. Any time they get off with what is causing diffusion all I have to do is say “Go back to the room with 400 kids in it, what would happen if you are looking at the 400 kids and the protein channel is the door between my room and Ms. C’s room?” Then they are back to something that they have a good understanding for and they can connect that knowledge. Yeah, I am a story teller and I like telling stories. (stimulated recall interview, Day 2)

Janis described her utilization of formative assessment during investigations, while students were working. She moved through the classroom, observing what students were doing during the potato stick investigation; asking questions to challenge their thinking. She explained:

So how did the water pass through the membrane and what caused it to move out of the potato stick that was in the salt water and yet, how is it that there was not much change in the potato stick in the distilled water? If anything the potato stick in distilled water got crisper it did not get limp. I am trying to elicit from them at least questions about what is going on. (pre-observation interview)

Questioning students and carefully noting their responses is an important aspect of Janis’ formative assessment. She questions students to gain insight into their thinking and

comprehension. Next, Janis utilizes feedback from students to inform her teaching. Janis explained:

I will have to go back to eliciting responses from them again until they get to the point where they recognize that there has to be a passage way for the water. There were still convinced in 6th hour that water was diffusing through the lipid bilayer. They have to see that, no, it can not do that. You know, this is not an essential piece; you can talk to them about diffusion and osmosis without that piece, but I think that it helps them to understand the mechanism. (stimulated recall interview, Day 1)

Janis combines questioning with analogies to guide students' thinking. She implemented an analogy focused on changes in *Elodea* cells resulting from osmosis when the *Elodea* leaf was placed in distilled water. In the analogy, she represents the cell as a block of jello and the central vacuole, within the jello block, as a water balloon. Next, Janis asked students to explain how the jello cell would change if additional water was placed in the balloon. Her goals were to elicit student thinking and support students as they construct their knowledge of osmosis. Janis explained:

When I talked to them about central vacuoles, I set up this little scenario of a soft, floppy cube that is filled with jello. I asked them what would happen if you put a water balloon inside the jello and filled it up, what would happen to the jello. So we keep going back to the jello. The *Elodea* and potato stick labs are to help them take what they know and really apply it (stimulated recall interview, Day 1).

Janis utilizes formative assessments to determine students' understanding. She explained that she relies upon feedback from these assessments to guide her decisions during a lesson. During the cell observation lab on Day 1 and the potato stick lab on Day 2, Janis relied upon student predictions to assess students' understanding and determine next steps in the lesson. Students shared their ideas to make sense of their observations during class discussions and interactive lectures. This strategy provided Janis with

valuable information about students' thinking in regard to their understanding of osmosis and diffusion.

Knowledge of Curriculum

Janis noted osmosis, diffusion, and the maintenance of homeostasis are identified by state Course Level Examinations (CLEs) and the district curriculum as key content for 10th grade general biology. Janis believes students learn most effectively when connections are made between students' prior knowledge and new content. Janis explained:

We have a lot of stuff to refer back to now. We can say "How did your potato feel when it was in the water. They did make connections with the central vacuole. All three classes made connections with the central vacuole. (stimulated recall interview, Day 2)

Janis' conception of curriculum is clearly focused on creating a big picture and making connections between concepts, lessons, and units. Her goal is to emphasize the connected nature of biological concepts. Janis reported "everything in biology is connected and nothing stands by itself" (stimulated recall interview, Day 2). She explained that she consistently focuses on relating concepts to student prior knowledge and life experiences. She consistently referred students back to graphics and animations of a cell membrane from PowerPoint lectures, and integrated these common threads into discussions of concepts related to the phospholipid bilayer (cell membrane), the relative concentrations of solutions, and the movement of water from high to lower concentrations. Janis explained:

Like the phospholipid molecule that I showed them today; they had seen a picture of a phospholipid molecule, we talked about phosphate heads and hydrophobic and hydrophilic sections. That was a one-time thing but if I were refer back to it over and over again. . . . It is just making multiple connections for them which

maximizes, I think, their ability to make some internal sense of the information. (stimulated recall interview, Day 2)

Janis explained students are able to envision the 'big picture' when they begin to make connections between concepts and gain insight into how living systems function. She explained:

What I want them to do is to think about the fact that something is leaving the potato stick that gets really limp and then I hope that somebody will ask what substance that was leaving the potato stick. I am hoping that after we talked a few days ago when we talked about the central vacuoles in plant cells and we talked about the fact that plants will wilt when their central vacuole loses water and starts to empty out; I hope that that connection will be made. I hope that somebody will make that connection. (pre-observation interview)

Janis explained that she designed her curriculum to move from "the bottom up" (pre-observation interview). Initially, Janis focused on the chemistry of water. She then expanded her focus to include cellular organelles and the role of water within the cell. She expanded the on cellular structures to include the diffusion of water into and out of the cell via osmosis through the cell membrane. She explained:

When we talk about diffusion and osmosis, we talk about what is going on with water so we are in that structure and we have gone from chemistry into the parts of the cells and now to diffusion and osmosis. (pre-observation interview)

When discussing tonicity [relative concentrations of dissolved solid in solutions] she planned to spiral back to the representations and investigations conducted by students during Days 1 and 2 of the observation. Janis explained her plans:

When we start talking about the tonicity of environments - hypotonic and hypertonic environments they have a reference. We can say "OK now you remember the potato slice in the salt water, what happened to the potato in the salt water? What happened to the potato slice in the distilled water?" That instead of my just drawing a picture on the board and saying this is what will happen if you place a cell in a hypertonic environment. I can say you remember what happened to the potato stick in the salt water. (pre-observation interview)

During the observation, Janis engaged students in explorations of osmosis through investigations into cells within Elodea leaves exposed to distilled water or saline and osmosis within plant organs (potato slices). In each instance, the exploration of osmosis preceded the explanation. Explanations generated through discussions in which students shared their predictions and observations of osmosis in cells or plant organs were supported by evidence collected during investigations. Hence, students were consistently challenged to make and test predictions of phenomena before explanations were generated.

Janis relies upon a significant array of curricular resources as evidenced by the Internet resources included in her PowerPoint, the investigations implemented into her lessons, and her future plans for teaching tonicity and other concepts related to osmosis and diffusion. She explained that even though her curriculum is largely guided by state CLEs and the district curriculum, she is continually searching for new investigations, activities, models, and manipulatives to enhance students' learning. Janis believes that concepts in biology do not and can not stand alone but are part of a much larger picture explaining the nature of life and living organisms. She noted by introducing the phenomenon first, prior to an explanation, she engaged students in exploring osmosis, making connections between their observations and existing knowledge, and constructing their knowledge of osmosis as a biological process important in maintaining homeostasis. By making connections between concepts, lessons, and units, Janis supports students as they construct a coherent understanding of life.

Janis' PCK for Teaching Diffusion and Osmosis

Janis demonstrated the ability to create teachable moments during which she integrated her subject matter knowledge, representations, instructional strategies, learners, curriculum and assessment to support students' construction of knowledge of osmosis and diffusion. A modified Magnusson et al. (1999) model of Janis' PCK for teaching osmosis and diffusion is shown in Figure 13.

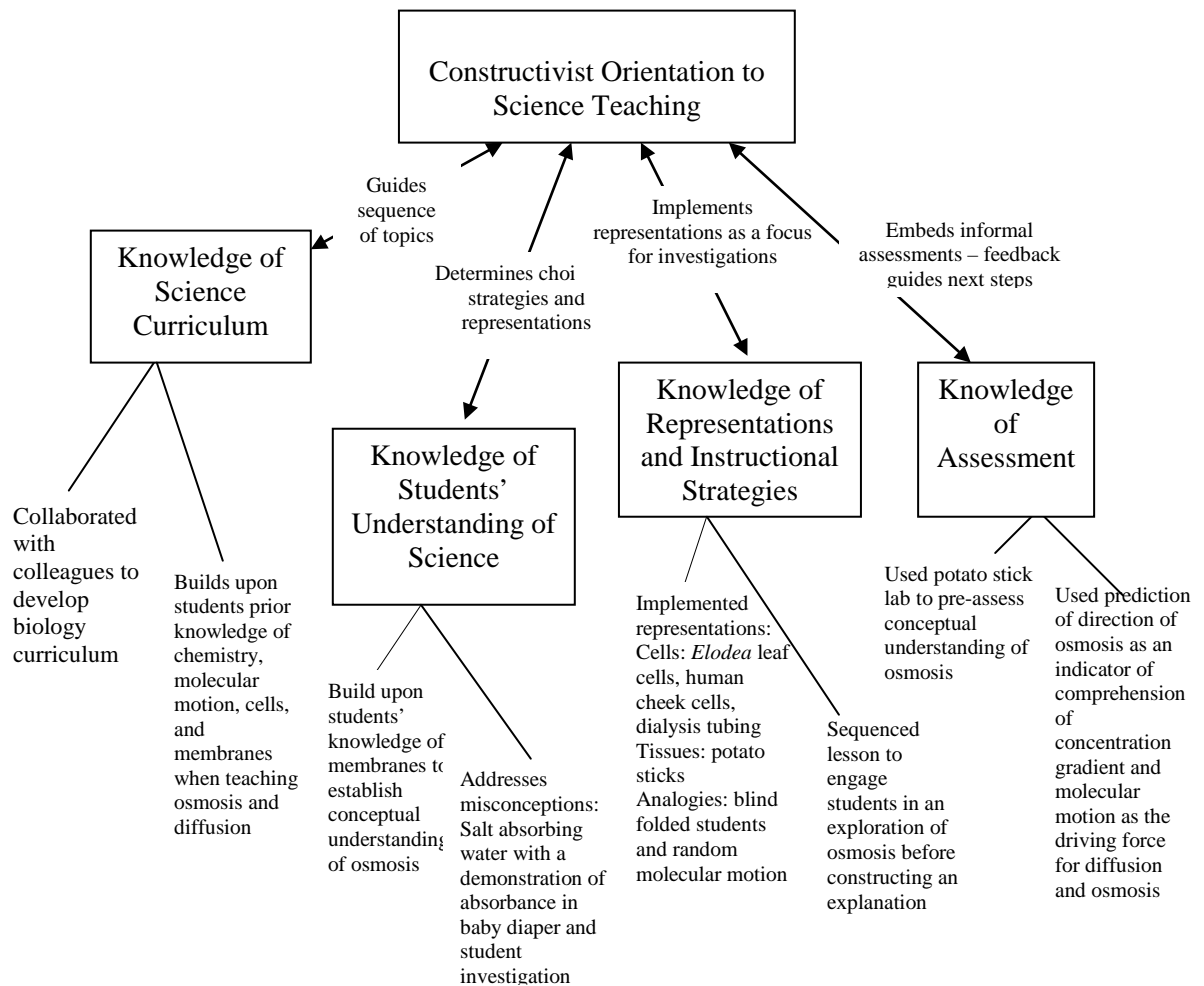


Figure 13: *Janis' topic-specific PCK*¹³

¹³Note: Modified from Nature, sources, and development of pedagogical content knowledge for science teaching (p. 99), by S. Magnusson, J. Krajcik, & H. Borko, 1999. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 95-132). Boston, MA: Kluwer.

The modified Magnusson et al. (1999) model identifies the nature of teacher knowledge Janis holds for teaching osmosis and diffusion. Janis describes her role as a facilitator and her overarching goal for teaching science as scaffolding student learning by making connections between prior knowledge and experience and the concept of osmosis. Janis implemented investigations in which students observed osmosis in *Elodea* cells, potato sticks, and Wisconsin Fast Plants. She implemented interactive lectures to draw out students' ideas, and explanations to make sense of students' experiences and construct their knowledge of osmosis; hence, Janis holds a constructivist orientation to science teaching.

Janis' beliefs about teaching and learning act as a filter, shaping the nature of representations, instructional strategies, assessments, and curricular sequence implemented into her lessons. She implemented analogies to assist students with their understanding of the cell membrane and random molecular motion as the driving force for osmosis and diffusion. Investigations into osmosis within plant cells and tissues provided insight into students' ongoing experience with Wisconsin Fast Plants and the role of water in living organisms. Janis introduced the concepts of diffusion and osmosis through investigations and implemented vocabulary terms (e.g., hypertonic, hypotonic, isotonic, and concentration gradient) as a means of explaining the movement of water from greater to lesser concentrations. Janis noted her goal in the *Elodea* and potato stick investigations was to prepare students for a more challenging investigation into osmosis and diffusion involving dialysis tubing as a representation of a cell during the following week.

Janis' integration of PCK components for teaching osmosis and diffusion is shown in Figure 14.

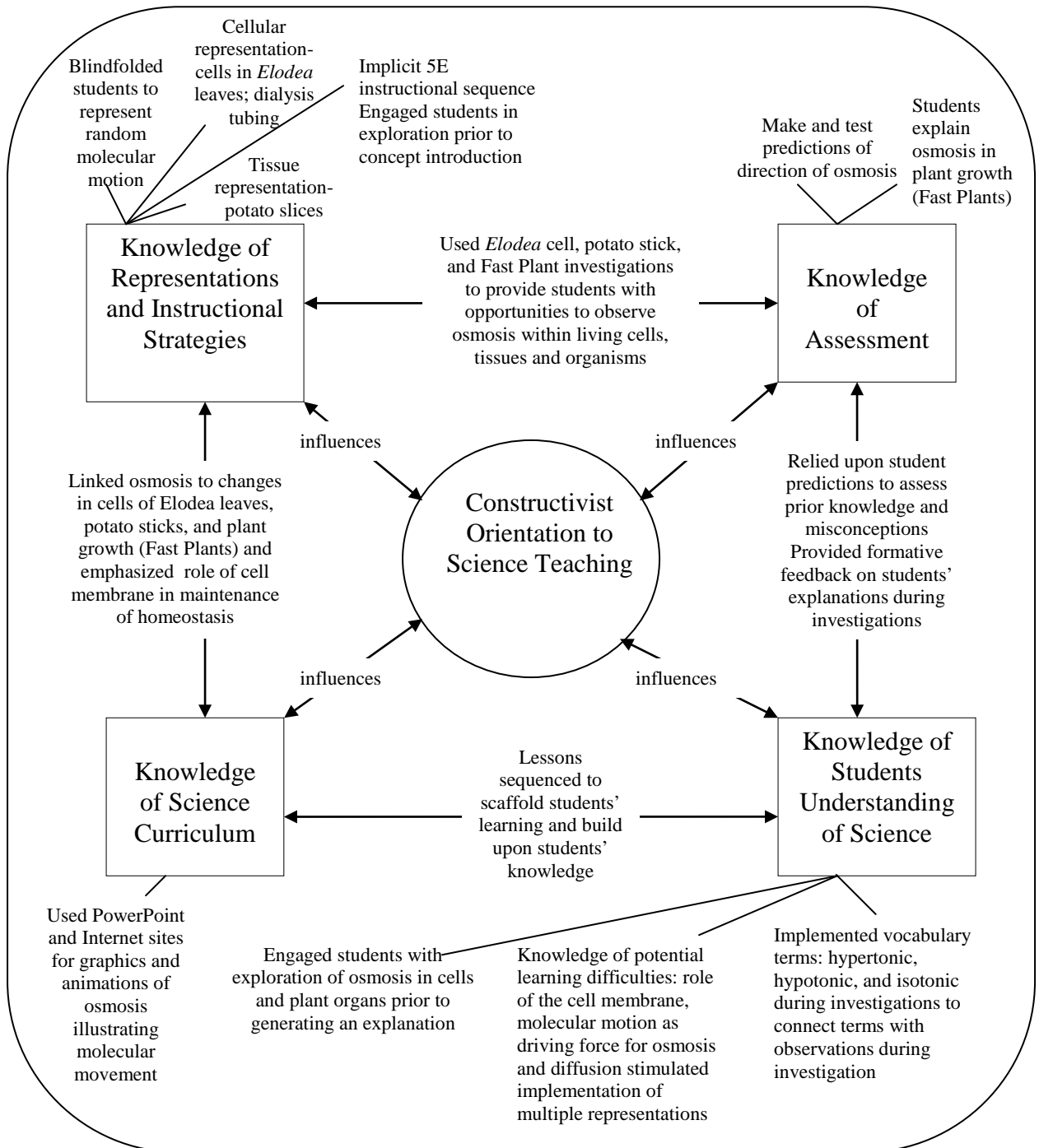


Figure 14: Integration of Janis' topic-specific PCK

Janis' integration of the components of her PCK for teaching diffusion and osmosis resulted in the creation of teacher knowledge specific for teaching diffusion and osmosis. There are four important features to note within this representation. First, Janis' orientation to science teaching is placed within center of the model. Her orientation to teaching science (described as her goals and purposes, perceptions of teacher and student roles, images of ideal teaching, and her view of science as a discipline) acts as a filter, influencing the integration of the components of her PCK. Second, connecting arrows indicate components of Janis' PCK are highly integrated and have a notable influence upon one another and her teaching. Each of the components influences the others as well as Janis' orientation. Third, examples taken from Janis' lessons included within the context of each component provides insight into her teaching. Fourth, brief connecting statements between components provide insight into Janis' integration of knowledge for teaching osmosis.

Because she believed students might have misconceptions about the direction of osmosis within living tissues, Janis implemented the potato slice investigation to elicit student ideas about the direction of osmosis within plant organs. She challenged students to make and test predictions and posed questions during the investigation and subsequent class discussions as formative assessments of students' conceptual understanding of osmosis. Janis relied upon student feedback to determine next steps in her lessons; she challenged students to test their belief that salt absorbs water and report their findings to the class. On the day following the observation cycle, Janis planned to illustrate water absorption with an investigation of water absorption by layers of material in baby diapers to address students' misconceptions about salt absorbing water. During the following

week, Janis planned to challenge students with an investigation into osmosis and diffusion in which a segment of dialysis tubing is a representation for a cell. Janis' knowledge of curriculum and curricular resources informed her understanding of students' prior knowledge based upon district science curriculum, the instructional sequence implemented during her lessons, and the availability of curricular resources. Janis integrated all components of her PCK to inform her teaching.

Content Representation

In Table 18, a Content Representation (CoRe) has been developed from Janis' observations and interviews to illustrate her topic-specific PCK for teaching diffusion and osmosis. The components of PCK are represented within the context of the CoRe and specific examples of instructional strategies and representations, assessments, potential student difficulties, and curricular considerations are included. When reading the CoRe, it is important to read individual columns (e.g. Big Idea A) from the top to the bottom vertically. The columns extend beyond a single page.

Table 18. *Content Representation for Janis*¹⁶

Considerations	Content Representation (CoRe)		
	Big Idea A	Big Idea B	Big Idea C
	Plasma membranes surround multiple cellular structures and are made up of a phospholipid bilayer.	Substances will diffuse along the concentration gradient from high to low concentrations.	Osmosis involves the diffusion of water across a semi-permeable membrane through specific protein channels.
Identify the learning goals for students within this lesson?	Students should understand: <ul style="list-style-type: none"> many cellular organelles are encased in a membrane that is identical to the membrane surrounding the entire cell. membranes are lipid-based, semipermeable structures. 	Students should be able to explain: <ul style="list-style-type: none"> the diffusion of all substances including water is dependent upon random molecular motion and collisions. the more concentrated a substance is, the greater the likelihood of molecular collisions and the movement of 	Students should be able to explain: <ul style="list-style-type: none"> water does not simply diffuse through a cell membrane. The hydrophobic nature of the membrane prevents random movement of water across the membrane. Protein channels [aquaporins] allow water to pass

	<ul style="list-style-type: none"> • membranes are selectively permeable. 	<p>substances from areas of higher concentration to areas of lower concentration.</p>	<p>through the membrane into the cell.</p> <ul style="list-style-type: none"> • osmosis is driven by random molecular motion. • the diffusion of water from areas of higher concentration to areas of lower concentration.
<p>Why is it important for students to know this content? [<i>Knowledge of Curriculum</i>]</p>	<p>Membranes are found in all living cells and share the following characteristics:</p> <ul style="list-style-type: none"> • membranes are semipermeable and surround cells to create a unique environment within cells. • membranes surround many, but not all, cellular organelles. • membranes are involved in biological processes: cellular respiration and photosynthesis. 	<p>Diffusion is critical for life and occurs in all life forms. Diffusion is characterized by:</p> <ul style="list-style-type: none"> • random motion and molecular collisions which drive movement of molecules from higher to lower concentrations. • substances enter and leave the cell through diffusion or osmosis. 	<p>Membranes have specific characteristics critical to their function:</p> <ul style="list-style-type: none"> • membranes have both hydrophobic and hydrophilic regions. • water diffuses through protein channels embedded within the membrane. • osmosis is the diffusion of water into or out of the cell through protein channels. • the direction of osmosis is dependent upon the concentration gradient of water within the cell and surrounding environment.
<p>Identify the difficulties and limitations associated with teaching this idea? [<i>Knowledge of students as Learners</i>]</p>	<p>Students may experience difficulty:</p> <ul style="list-style-type: none"> • understanding the movement of materials through a plasma membrane. • accurately predicting direction of osmosis. • in their perception of random molecular motion as the driving force for osmosis and diffusion. • in their understanding that membranes are semipermeable. 	<p>Students may not grasp the importance of relative concentrations in determining the direction of osmosis:</p> <ul style="list-style-type: none"> • understanding that substances diffuse from high to lower concentrations. <p>Students may find vocabulary challenging:</p> <ul style="list-style-type: none"> • vocabulary is unique: <ul style="list-style-type: none"> ○ hypertonic, hypotonic, and isotonic. 	<p>Students may not grasp the role of water in living organisms:</p> <ul style="list-style-type: none"> • all forms of life require water. • osmosis occurs in all living organisms regardless of the complexity or size of the organism.
<p>Identify knowledge of students' thinking which influenced the teaching of this idea. [<i>Knowledge of Students as Learners</i>]</p>	<ul style="list-style-type: none"> • Students not likely to envision random molecular movement as driving force for diffusion and osmosis. 	<ul style="list-style-type: none"> • Students' thinking is not clear in terms of why water moves from area of high to low concentration. 	<ul style="list-style-type: none"> • Students prior knowledge of the relationship between salt and water might indicate that salt absorbs water from other substances.

<p>Teaching strategies and representations implemented and particular reasons for using these strategies to engage students with this idea. [<i>Knowledge of instructional strategies and representations</i>]</p>	<p>Representations:</p> <ul style="list-style-type: none"> • Computer animations of diffusion and osmosis provide students with concrete examples of abstract concepts. • Students can predict changes in the direction of osmosis when changes in relative concentrations are made within the computer animation. • Floating ball analogy: Balls placed in a bathtub of water float on water surface to create a floating membrane separating the water from the air. • Computer representations of cell membrane in the PowerPoint clarified membrane structure and function. 	<p>Diffusion analogy:</p> <ul style="list-style-type: none"> • Blindfolded students moving randomly result in collisions and gradual movement from areas of greater congestion to areas of lesser congestion. <p>Representations:</p> <ul style="list-style-type: none"> • Direction of osmosis is evident in <i>Elodea</i> cells. • Direction of osmosis is evident in potato slices. <p>Potato slices investigation:</p> <ul style="list-style-type: none"> • Students make and test predictions of direction of osmosis within potato slices placed in distilled water and a concentrated saline solution. 	<p><i>Elodea</i> investigation:</p> <ul style="list-style-type: none"> • Students observed osmosis at the cellular levels through microscopic observation of <i>Elodea</i> leaf cells in distilled water or a saline solution. <p>Potato slice observation:</p> <ul style="list-style-type: none"> • Students observe changes in potato slices placed in saline and distilled water- used as a discrepant event. <p>Wisconsin Fast Plants (Fast Plants):</p> <ul style="list-style-type: none"> • Students observe changes in Fast Plants and explain wilting of plants in water deficient environment.
<p>Identify ways of ascertaining that students understand concepts taught. [<i>Knowledge of Assessment</i>]</p>	<ul style="list-style-type: none"> • Student predictions of direction of osmosis in cells and tissues reveal knowledge of cell membranes as semipermeable. 	<ul style="list-style-type: none"> • Student responses to questions about the direction of osmosis into or out of cells. • Students explain the role of water in plants in terms of Wisconsin Fast Plants. Student explanations of Fast Plant wilting reveals understanding of the movement of water through osmosis out of plant cells. 	<ul style="list-style-type: none"> • Teacher questions during investigations revealed students' understanding of concepts. • Students' predictions of direction of osmosis in potato slice investigation revealed students' thinking and conceptual understanding of phenomena.

The CoRe (Loughran et al. 2006) is an overview of Janis' PCK for teaching diffusion and osmosis. The description is reflective of her constructivist teaching practice.

¹⁶Note: Modified from *Understanding and developing science teachers' pedagogical content knowledge*, by J. Loughran, A. Berry, and P. Mulhall, 2006, p. 28. Rotterdam: Sense Publishers.

Jason's Case Profile

Jason's Vignette: Talk Like a Scientist

“Okay guys, the list of lab partners is on the whiteboard; check to see who you are working with today. Also remember to pick up your lab handouts before you sit down,” Jason explains as students enter his classroom.

It is October 28th, and the spirit of Halloween is alive and well in Jason's classroom. Refrains of *Monster Mash* echo through the room as students quickly enter from the hallway. The Smart Board, in the front of the room is decorated for Halloween with a bright orange background, black text identifying the plans for the day beginning with an investigation into osmosis and diffusion. There are images of a waving mummy, a smiling skull, and flying bats on the Smart Board to capture the essence of the season.

“Wow, this is cool!” a student comments as he moves to his seat.

“Yeah, like what is going on today?” a student asks as she opens her notebook.

“Hey, it is my Halloween theme,” Jason explains as he greets students entering the room. Jason has an imposing presence; he is a large man with a booming voice. Clearly, he cannot be ignored. The tardy bell rings and students are seated.

“Okay, listen up, we are going to go over a few things before we begin our investigation today” Jason tells the students. “Take out your highlighters so that you can highlight important steps on your lab handout. Today we are going to investigate osmosis and diffusion and we are going to use dialysis tubing to represent a cell,” Jason explains. He looks around the classroom and asks, “What is the first thing you will do during the investigation?”

“I know,” a student raises his hand. He explains, “First we are going to make a cell by tying off one end of the dialysis tubing.”

“Yeah, then it says we are going to pour a solution of water, starch, and glucose into the tubing,” the student comments as the other students follow along on their lab handouts.

“Then what will you do?” Jason asks.

“Okay, we are going to tie off the other end of the tubing and put the tubing into a beaker of water and iodine,” a student responds.

“Okay, take a minute to remember the terms solute and solvent; we have talked about these terms before. What do the terms mean?” Jason asks as he looks around the room.

“A solute is something dissolved in a solution,” one student answers.

“Yeah, and a solvent is what the solute is dissolved in; like water in a sugar and water solution,” another student answers.

“Good job, remember to use these terms when you are answering your lab questions or explaining something to the class. Remember, I want you to use these terms and talk like a scientist,” Jason explains.

“Look at your lab sheet; do you see other words that are confusing for you?” Jason asks.

“Yeah, like what is a permeable membrane?” asks a student in the back of the room.

“Good one, Jill. Okay, what does permeable mean?” Jason asks as he writes the term on the Smart board.

“It means that things can pass through the membrane” a student responds.

“Great,” Jason exclaims as he writes the definition on the board. “So, if permeable means that things can pass through, what does semipermeable mean?”

Several students raise their hands and Jason calls upon a student in the front row. The student explains, “Semipermeable means that only some things can pass through and other things cannot.”

“Super, so let’s say that you go to a club and there is a bouncer standing at the doorway; he will determine who gets in and who does not, so not everyone can get in,” Jason explains as he writes the definition on the board.

“Now, what if a membrane was freely permeable?” Jason asks.

A student explains “That means that anything can pass through it.”

“Okay, good. But what if a membrane is nonpermeable?” Jason asks.

Another student explains, “That means that nothing can pass through it.”

“Now, when we talk about this lab or when you write answers on a test. I want you to use the words solute, solvent, solution, permeable, semi-permeable or impermeable,” Jason explains. “I want you to talk like a scientist and that means that you will use the appropriate terms when we talk about this.”

“All right, take your lab sheets and move to your lab stations, check the whiteboard if you are not sure who you will be working with today,” Jason states as he directs the students. The students quickly move to the lab stations and the lab begins as Jason demonstrates how to tie off the dialysis tubing.

“Now, remember what we said earlier, we are going to place the dialysis tubing you and your partner have prepared into a beaker containing a solution of iodine and water,” Jason explains.

The students work quickly to tie off the dialysis tubing and fill the tubes with a starch and glucose solution and tie off the opposite end.

“Do we use the glucose testing strips now?” a student asks.

“Yes, I want you to test the solution in the beaker and the solution you placed in your dialysis tubing” Jason explains. “Remember, the glucose testing strips will change colors if glucose is present.”

“Hey, Mr. L., only the solution we put into the dialysis tubing has glucose; the other one does not,” a student comments as lab groups quickly test both solutions for the presence of glucose.

“Okay, I need everyone’s attention,” Jason tells the students as he prepares to add several drops of iodine to a beaker of starch. After he adds several drops of iodine to the starch solution there is a dramatic change as the starch solution turns from an opaque white to a black color.

“That is way cool!” a student claims.

“Iodine is an indicator because it will react with the starch to create a dark blue or black color change” Jason explains.

“Cool, we are using two indicators then, one for glucose and another for starch,” a student notes.

“That is right, Chris, now you will be able to see if either solution changes during our investigation,” Jason explains. Students place the dialysis tubes into beakers of distilled water and iodine.

“Now, I want you to predict what is going to happen to both solutions, the solution of iodine and water in the beaker and the starch and glucose solution in the dialysis tube bag,” Jason directs the students. The room fills with a low level buzz of conversation as lab groups discuss predictions.

“When you have made and recorded your predictions, move back to your seats and we will talk about the topic for the day, osmosis and diffusion,” Jason explains. Suddenly, the melodic sounds of *Monster Mash* fill the room as students collaborate with peers to make their predictions. As students complete the task, they gradually return to their seats.

Background and Context

Jason is a veteran biology teacher. He has been teaching general biology and dual credit biology at Carlville High School for the past 15 years. Carlville High School is the only high school in a small Midwestern community. According to the 2000 Census, Carlville is a rural community with a population of approximately 25,000 residents (U.S. Census, 2000). School statistics from the Department of Elementary and Secondary Education (DESE) indicate Carlville High School includes grades 9 through 12 with ratio of 18 students per teacher, consistent with the state average for the ratio of students per teacher (DESE, 2008). Carlville High School is on a block schedule which includes 90 minute class periods with classes meeting every other day.

Jason’s classroom is part of a new addition to the high school completed in 2005.

The room is partitioned into a traditional classroom and a laboratory area. The traditional classroom contains five rows of student desks with five desks in each row. The laboratory area consists of six laboratory stations complete with running water, sinks, and electrical outlets. A Smart Board used for PowerPoint notes, investigation protocols, seasonal images, and music is on the wall in the front of the room; a traditional whiteboard lines the wall on the right side of the room.

Jason is also a veteran coach and is currently an integral member of the coaching staff for three sports including: football, basketball, and track. He believes coaching creates an opportunity to interact with students outside of the academic realm. He explained:

I coach three sports and I have contact with all of these kids as a coach, a spectator, or a fan. One of the things I like about a small community is that the rapport with the students is phenomenal. . . . I know all of these kids and their parents personally. I could call and talk to their parents and they may not want to talk to me but I could call them by their first name and they would know exactly who I was when I talked to them. This is one of the things that make me a better teacher because I know the kids and their families. (stimulated recall interview, Day 1)

Jason believes the small community in which he teaches and coaches offers a significant advantage in terms of the contact he has with students and their families and a major asset for his effectiveness as a teacher. By knowing his students and their families, Jason believes he has a better understanding of his students as individuals and this knowledge makes him a better teacher. Jason believes he can work closely with students and their families to affect change in students' behavior and performance in his classes.

Orientation to science teaching

Jason's orientation to science teaching is described by addressing aspects of his instructional practice in terms of his: (a) goals and purposes of science education,

(b) interpretation of teacher role, (c) interpretation of student role, (d) ideal images of teaching, and (e) view of science as a discipline.

Goals and purposes of instruction. Jason identified three overarching goals for his teaching. His first goal is to challenge his students with explorations of scientific concepts and encourage students to ask and answer questions while constructing their knowledge of biology. Jason's second goal is to engage his students in explorations of phenomena with technology and challenge them to solve realistic problems in the form of computer-based challenges. He noted students are comfortable with technology and become active participants in learning opportunities which challenge them to apply their knowledge to solve problems posed by computer software programs. He explained, "I explore new ways to teach and I spend more time on my teaching process than content. In the future I cannot see technology going away, I just see it getting better and better," (stimulated recall interview, Day 2). Jason believes that students are easily engaged with technology which provides them with a "performance enhancement type thing in that they [the students] will actually have to use what they learned" (stimulated recall interview, Day 2). His third goal is to act as a resource and provide content knowledge for his students through PowerPoint notes, lectures, class discussions, informational handouts, and handouts for laboratory investigations. Jason explained that he does not use a textbook; therefore, his PowerPoint notes and informational handouts are designed as a source of current content knowledge. He explained "I am acting like a resource for my students" (pre-observation interview).

On Day 1 of the observation, Jason provided students with an opportunity to explore osmosis and diffusion through a laboratory investigation. A dialysis bag,

representing a semipermeable membrane, was filled with a glucose and starch solution and placed in a beaker containing distilled water and iodine. Jason implemented the laboratory investigation as an exploration of osmosis, diffusion, and membrane permeability prior to introducing the concepts. Jason explained his reasoning for implementing the laboratory investigation:

My class is just getting ready to start cells. When we start cells, we start with the cell membrane. So what we are going to do today is that we start cells today we will begin with a lab. A typical lab of osmosis and diffusion through the cell membrane with iodine and starch, as the iodine passes through the membrane it turns the starch solution black. (Pre-observation interview)

Jason explained he included analysis questions following the investigation to challenge students to integrate their observations from the investigation with their understanding of key concepts related to membrane permeability, diffusion, and osmosis. Through this approach, Jason believed that students would develop a clear understanding of how and why diffusion and osmosis occur in living cells. He stated:

After we finish that [the osmosis and diffusion lab] we will come back and I will give them a homework assignment on homeostasis on why plants and animals have to do osmosis and diffusion. From the homework they will have to use the information they got from the lab and the information they got from the notes on homeostasis. (pre-observation interview)

On Day 2, students were challenged to apply their knowledge of osmosis and diffusion to predict the direction of osmosis in scenarios presented by the *Osmobeaker* computer program (Meir et al. 2004). Jason identified three purposes for implementing the *Osmobeaker* program (Meir et al. 2004) into his lessons. First, he explained that the program allowed his students to actually “see how many molecules there were in each compartment [within the cell and the bloodstream]” (stimulated recall interview, Day 2). Hence, students were able to observe osmosis at the molecular level. Second, Jason

wanted his students to use vocabulary terms in their writing. He explained, “I want them to use the terms that we were talking about during the lecture in explanations such as hypertonic, hypotonic, and isotonic” (stimulated recall interview, Day 2). Third, Jason wanted his students to understand the relationship between solute and solvent in two different solutions could be expressed mathematically. He noted that he wanted his students to understand “the math part and how to figure concentrations and how to figure percentages, ratios and stuff like that” (stimulated recall interview, Day 2).

Jason’s goals and purposes for instruction indicate an approach to science teaching in which students are initially engaged in an exploration of osmosis and diffusion prior to an explanation of the concepts. Jason supported students’ understanding of diffusion and osmosis by reviewing key vocabulary terms (e.g., hypertonic, hypotonic, isotonic, concentration gradient) following the osmosis and diffusion investigation on Day 1. He encouraged students to use the terms in their responses to analysis questions following investigation. Thus, his purpose during Day 1 was to provide students with content knowledge and challenge them with a laboratory investigation during which both osmosis and diffusion were clearly observable. On Day 2, Jason challenged his students to apply their understanding of osmosis and diffusion to a problem-based scenario posed in the *Osmobeaker* computer program (Meir, Stal, & Maruca, 2004). Hence, Jason’s purpose was to provide scaffolding for student learning on Day 1 and on Day 2 challenge students to apply their understanding to solve problems related to osmosis.

Perception of teacher role. Jason’s perception of his role as a science teacher is to be a concerned adult first and an educator second. He explained that by being a caring

adult, he was able to engage more of his students to take an active role in learning about science. He noted:

Well, I think educator is pretty important but I think before educator you have to be a caring adult. . . . I feel that I have accomplished more with a student at the end of the class period not if he has comprehended all of my lesson content but if he has tried to comprehend all of my lesson content.” (stimulated recall interview, Day 2)

Jason perceives his role as capturing students’ interest, engaging students in learning, and, ultimately, turning students on to science. He explained: “I think as long as they still have interest in the content and in school you have succeeded. When you lose their interest, you are going to lose them” (stimulated recall interview, Day 2).

Jason believes his role is defined by his goals for student learning and noted his role shifts throughout the lesson to support the learning goals for his students. When Jason challenged his students to apply their knowledge within the context of a laboratory investigation, he took on the role of a facilitator. He reported: “I think my role changes as the lesson goes on. . . . As you can see in the first part of the lab I am the resource and in the second part of the lab they are on their own” (stimulated recall interview, Day 2). As he moved around the room during the lessons on Days 1 and 2, Jason’s role was that of a facilitator answering students’ questions with new questions to guide their thinking. He encouraged students to collaborate with peers, collect data, and develop conclusions supported with evidence from the investigation. Jason perceives his teacher role as changing within the context of the lesson along with the learning needs and learning difficulties of his students.

Perception of student role. Jason described the role of students as being open to learning new concepts, ideas, and explanations. He further described students’ role as

being prepared to apply knowledge to solve unique problems in novel situations and taking an active role in learning. Jason explained:

I think they [students] have to be sponges. I think that they have to take whatever information you give them and expand upon it and search for more information on that content. I think that when I am done with them I just do not want them to know what osmosis and diffusion are; I want them to be able to solve problems with that very process. (stimulated recall interview, Day 2)

Jason believes students' learning is enhanced and they develop a clearer understanding of how scientific concepts relate to their lives when challenged with real-world problem-based scenarios. He related a story about one of his students and how the student applied his understanding of osmosis, diffusion, tonicity (amount of dissolved solid with solutions) to his mother's IV solution during her recent hospitalization. He explained "I like to use past experiences and experiences that they have had in this community. That is the good thing about being in a small school; you kind of know what is going on" (stimulated recall interview, Day 1).

Jason's perception of the student role is multifaceted. He stressed that students must be prepared to learn, prepared to work collaboratively to answer questions and develop explanations, to learn from one another, and ultimately to apply their knowledge to solve realistic problems. He believes that realistic challenges engage students in learning and encourages them to take a more active role in their own learning.

Ideal images of teaching. When asked how he preferred to teach, Jason indicated that his preference was to provide learning experiences for his students through problem solving, laboratory investigations, and technology in the form of computer software packages that challenge students to apply their understanding to real-world problems.

Jason explained that his ideal images of teaching biology emerged from his experiences as a college student. He noted that as a college student his involvement with research conducted by his professors provided the most meaningful learning experiences. Jason believed that being engaged in doing science is critical to effective teaching and learning. He explained his views on teaching by stating:

In college I found that it was not the lecture that got me going in science. It was the stuff I was doing outside of class. It was capturing and banding birds and marking quadrants. Those are the things and in microbiology growing stuff on agars. Those are the things that were important to me and those are the things that got me interested in what I am doing. (stimulated recall interview, Day 2)

Jason explained that the dialysis bag laboratory investigation on Day 1 provided students with an initial exploration of diffusion and osmosis. Later in the lesson, the interactive lecture and discussion provided an introduction to membrane structure, function, and permeability. Jason planned to scaffold students' understanding of concepts related to osmosis and diffusion (e.g., membrane permeability and the diffusion of substances from high to low concentrations) during Day 1 to support problem-solving challenges during Day 2 through the *Osmobeaker* computer software (Meir et al. 2004).

During Day 2 students worked with the *Osmobeaker* software (Meir et al. 2004) to manipulate an IV solution and investigate osmosis or the diffusion of water into or out of the red blood cell based upon changes made in the IV solution entering the bloodstream. Thus, students had the opportunity to conduct an investigation of osmosis and diffusion in which the diffusion of individual molecules were represented and observed. He explained his ideal lesson:

I try to incorporate three things into every lesson; I try to incorporate some type of lecture, some type of thing in which I am presenting information, it may not be a traditional lecture but some way that I am presenting information. I try to incorporate some type of hands on activity like a lab, and I try to incorporate

technology. So I try to incorporate those three things into every lesson. (pre-observation interview)

Jason consistently referenced his goal of implementing technology into his teaching. He explained:

The district just went through a big technology push about two years ago and it finally came through this year with the Mac-carts. We have Mac-carts and I have microscopes that connect to the Macs. I have a Smart Board. We have Lab Quest, little Palm Pilots that we use to record our data. I try to incorporate as much technology as I can now because the kids respond more to technology; they are all computer and cell phone oriented. (pre-observation interview)

Jason estimated the percentage of time within the context of each lesson dedicated to laboratory investigations, lecture/discussion, and virtual investigations. Jason explained:

I use a lot of technology and I like hands on. I do a lot of hands on. My lessons are about 25% lecture and that is me being the resource and that is because I do not use a book. I would rather act as the resource because then they [kids] know what I want. About 75% of them using that to solve problems; so probably 25% lecture and 75% experiments. (stimulated recall interview, Day 2)

Jason's goal is to design a learning environment in which students are challenged to solve problems and find answers through laboratory investigations and technology in the form of computer software. Jason explained the inclusion of technology in his lessons was based upon his belief that students are readily engaged with technology and, as a result, learn more effectively.

View of science as a discipline. Jason views of science as a discipline demonstrate his belief that evidence is critical in science. He explained:

I am incorporating their experiences and I expect them to use that when they explain something to me. If I want them to think like a scientist then they have to draw upon their experiences they had to write like a scientist by using their experiences as evidence to support their ideas. (stimulated recall interview, Day 1)

Jason required students to make and test predictions through the laboratory investigation on Day 1 and the computer challenge on Day 2. He consistently challenged students to support their explanations with evidence. He defined science as having a unique language and emphasized vocabulary. Jason expected his students to “talk like scientists” (stimulated recall interview, Day 1) by using vocabulary appropriately in their explanations. He explained:

I really press my students that I want them to start talking like a scientist. Like we did a lab on cohesion and the kids kept on telling me that the molecules were ‘sticking’ together. Well “sticking together” is a term that I used in third and fourth grade, I want to hear about hydrogen bonds and oxygen bonds. I want you to talk like a scientist. (pre-observation interview)

He believed the accurate implementation of vocabulary terms in students’ explanations enhanced their understanding of the concepts under study.

Jason views science as a way of knowing based upon evidence. He challenged students to make predictions prior to beginning the investigations on Day 1 and 2. Next, students used their observations to test their predictions. Jason required students to explain their observations when responding to laboratory analysis questions using evidence gathered during the investigations to support or refute their prediction. He explained: “I have a critical thinking section where they [students] have to use what they have learned in the notes and so forth” (pre-observation interview). Throughout both lessons, he insisted that his students support their ideas about diffusion and osmosis with evidence gathered during the investigation.

Summary of Jason’s orientation to science teaching. Jason’s orientation was informed by his experiences as a student and as a teacher. First, his experience as a student researcher in college encouraged an interest in scientific investigations. Second,

his experience with teaching high school biology resulted in exploring ways to actively engage students in learning. This exploration led to the inclusion of technology to challenge students to apply their knowledge to solve real-world problems. Teaching tenth grade biology and coaching three sports within the context of a small, rural community informed his goals and purposes for teaching biology as well as his perception of student and teacher roles. Sources which influenced Jason's orientation to science teaching are shown in Figure 15.

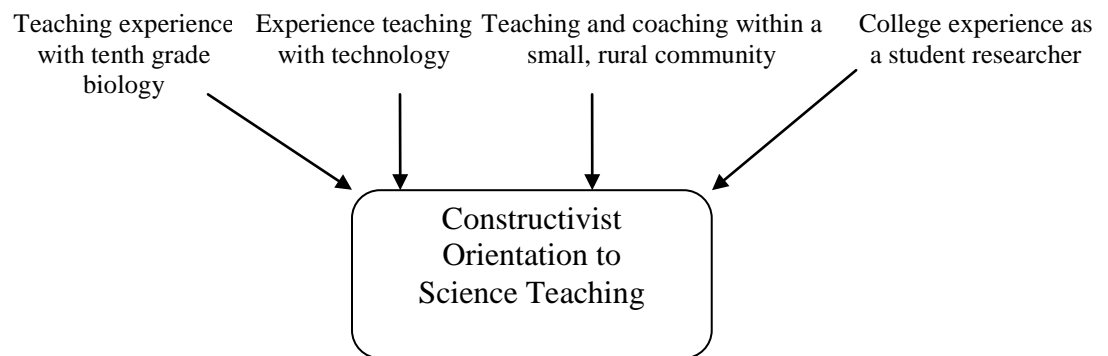


Figure 15: *Sources of Jason's orientation to science teaching*

I describe Jason's orientation to science teaching as constructivist for several reasons. First, he followed a 5E instructional sequence. Jason initially engaged students with explorations of osmosis prior to introducing the concept. Before beginning the exploration, students predicted the direction of osmosis and tested their predictions by observing evidence of the direction of osmosis within the model. Second, Jason drew upon students' experiences when developing explanations for osmosis. He asked students to share the rationale for their predictions and reflect upon their observations to explain the direction of osmosis. Third, Jason structured his lessons to build upon students' experiences with the concepts to construct their knowledge of osmosis. On Day 2, Jason drew upon students' experiences with osmosis on Day 1 to predict changes in a virtual

red blood cell when the concentration of water in the virtual IV solution was increased. Jason designed lessons to support students with the construction of their knowledge of osmosis.

Lesson Plan

Day 1 of the observation began with Jason reviewing the laboratory investigation for osmosis and diffusion. The investigation involved placing a starch and glucose solution in dialysis tubing which represented a cell, and next, placing the dialysis tubing in a beaker of distilled water and iodine. An overview of Jason’s lesson for Day 1 of the observation is shown in Table 19.

Table 19. *Jason’s lesson plan for Day 1*

	Activity		Description
Day 1	Introduce protocol for dialysis tubing investigation	Engage	Teacher: <ul style="list-style-type: none"> • Reviews protocol for osmosis and diffusion laboratory investigation
	Student predict changes in dialysis tubing and beaker solutions		Students: <ul style="list-style-type: none"> • Highlight key terms as Jason reviews the procedure • Make predictions of changes in the dialysis bag and beaker solutions
	Students set up dialysis tubing investigation	Explore	Students: <ul style="list-style-type: none"> • Pour the starch/glucose solution into the dialysis tubing • Test for the presence of glucose • Place dialysis tube in beaker containing an iodine solution • Predict changes in beaker and dialysis tubing solutions
	Students observe changes in dialysis tubing and beaker solutions to test their predictions	Explore	Students: <ul style="list-style-type: none"> • Test for the presence of glucose in tubing and beaker • Note changes in color and volume • Collaborate to answer lab analysis questions • Present answers to class
	Whole class discussion and PowerPoint lecture in which students share predictions, observations, and explanations	Explain	Students: <ul style="list-style-type: none"> • Share predictions and investigation outcomes • Construct explanations using supporting evidence from investigation Teacher: <ul style="list-style-type: none"> • Introduces vocabulary

After completing the set up for the investigation, students predicted the direction of osmosis. Next, Jason engaged students with a discussion focused on the structure of

the cell membrane, membrane permeability, solubility, and solutions. Students shared their predictions for the dialysis investigation and answered questions posed during the lecture. Following the discussion, students returned to their laboratory investigations and noted changes within the dialysis bag and the solution in the beaker. Students noted the solution within the dialysis bag increased in volume and underwent a color change from opaque white to dark blue/black indicating that distilled water and iodine diffused into the dialysis bag from the solution in the beaker. The solution within the beaker tested positive for glucose indicating that glucose diffused out of the dialysis bag and into the solution within the beaker. Thus, students were able to observe two distinct changes related to diffusion and osmosis within the dialysis bag and beaker solutions.

During an interactive PowerPoint lecture, student teams shared the results of their dialysis tubing investigation with the class. Jason asked students to explain the presence of glucose in the beaker solution and the increased volume and darkened color of the starch solution within the dialysis tubing. Students noted the dialysis tubing membrane was not permeable to starch but was permeable to water and iodine and supported their claim by noting an increase in the volume of the dialysis bag contents and the color change indicating starch remained inside the tubing, however, water and iodine were able to diffuse through the membrane into the tubing. Students explained the dialysis membrane was also permeable to glucose by noting the presence of glucose in the beaker solution and in the dialysis tubing solution. They concluded the dialysis membrane was semipermeable allowing smaller molecules such as, water, glucose, and iodine to diffuse into the tubing; however, starch, a larger molecule, remained within the tubing. Jason identified key vocabulary terms including hypertonic, hypotonic, isotonic, and

concentration gradient. He related the terms to students' observations and encouraged student to integrate the vocabulary into their explanations.

An overview of Jason's lesson for Day 2 of the observation is shown in Table 20.

Table 20. *Jason's lesson plan for Day 2*

	Activity		Description
Day 2	Overview of <i>Osmobeaker</i> software Review of basic mathematics	Engage	Teacher: <ul style="list-style-type: none"> • Explanation of <i>Osmobeaker</i> computer software • Review calculation of percentages and ratios • Review vocabulary terms (hypertonic, hypotonic, isotonic, semipermeable, concentration gradient, diffusion, and osmosis)
	Investigate osmosis through computer software	Explore Extend	Students: <ul style="list-style-type: none"> • Apply knowledge of osmosis to the <i>Osmobeaker</i> computer program • Follow the guidelines on the handout to manipulate the program • Answer questions about the direction of osmosis-water movement into or out of the red blood cell • Calculate percentages of dissolved solid and water in the red blood cell and the IV • Use ratios to identify relative concentrations of water within the IV and the red blood cell • Test predictions with each step in the program
	Students discuss analysis questions and explain findings	Explain	Students: <ul style="list-style-type: none"> • Complete analysis questions • Explain and justify answers to questions

The lesson on Day 2 was very different from that on Day 1 in that students were expected to successfully apply their knowledge of cell membranes, relative concentrations, vocabulary terms (hypertonic, hypotonic, isotonic, and concentration gradient) and osmosis and diffusion to a realistic, virtual model of a red blood cell. Students were asked to predict changes in the direction of water movement between the virtual red blood cell and a virtual intravenous (IV) solution while manipulating concentrations of dissolved solids in the IV solution. Jason challenged students to calculate relative concentrations of dissolved solids within the cell and the IV solution in an effort to build connections between mathematics, the relative concentrations of dissolved solids, and the direction of osmosis. Jason's goal was to help students employ

mathematics to predict the direction of water movement along a concentration gradient while gaining a micro view of osmosis based upon relative concentrations of dissolved solid identified within the program. Jason designed the lesson on Day 1 to support students' understanding of osmosis and diffusion and to prepare students to apply their knowledge when working with the *Osmobeaker* computer program (Meir, Stal, & Maruca, 2004) on Day 2.

In the following sections, I describe the knowledge components of Jason's PCK including his knowledge of: representations and instructional strategies, students' understanding of science, assessment, and curriculum.

Knowledge of Representations and Instructional Strategies

The lesson on Day 1 engaged students with an exploration of osmosis and diffusion through the dialysis tubing investigation before introducing diffusion and osmosis through a PowerPoint lecture. Jason explained:

They will start the lab not knowing what they are doing. . . . They have talked about diffusion a little bit. That lab takes a little while to transpire and while the lab is transpiring we will go back to the smart board and we are going take a little bit of notes on what makes up the cell membraneWhen we get done we will go back and get the results and from the results then I give them post lab questions where they have to describe what happened. (pre-observation interview)

After students set up the osmosis and diffusion investigation and predicted changes in the solutions within the dialysis tubing and beaker, Jason transitioned to a discussion for which he identified three goals including: (1) sharing predictions for the outcome of the investigation, (2) identifying Brownian motion (random molecular motion) as the driving force for diffusion and osmosis, and (3) clarifying the semipermeable nature of the cell membrane. During the discussion, Jason implemented an analogy to explain the nature of a cell membrane. He noted: "Think about a club with a bouncer. It is the bouncer who

determines who gets into a club just as the cell membrane determines what is able to enter or leave the cell” (Jason, Day 1). He identified the dialysis tubing membrane as semipermeable and explained the direction of diffusion and osmosis as a consequence of the relative concentrations of tubing contents and the iodine solution in the beaker. Jason explained:

Well like I said before, this is a lab that we are doing without a lecture or prior knowledge or instruction to it. So I wanted to get some understanding down about permeability and things that can pass and things that cannot pass and then when I get the lab results I am going to expect that the students will use the word nonpermeable if things cannot pass through the membrane. (stimulated recall interview, Day 1)

Following the discussion, students observed the dialysis bag for changes in color, measured the amount of liquid to determine if water entered or left the bag, and used a glucose strip test to determine if glucose diffused out of the dialysis bag into the iodine solution in the beaker. Jason challenged students to explain their observations in analysis questions: “In one of the post lab questions students are asked if glucose passed through the dialysis tube membrane and how do they know that this happened?” (stimulated recall interview, Day 1). Jason drew a diagram of the dialysis tubing in a beaker (see Figure 16) on the Smart Board and asked students to indicate the direction of movement of glucose, water and iodine.

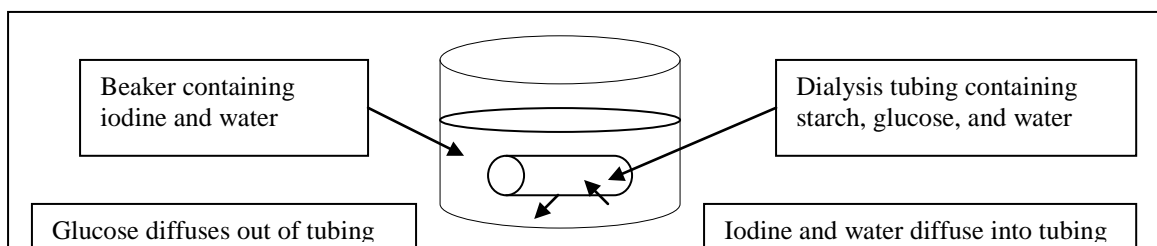


Figure 16: *Whiteboard diagram of dialysis investigation*

Jason explained his rationale for drawing the diagram by stating:

By drawing the picture we could easily show what was going in which direction. When it comes to diffusion and osmosis, they tend to think that everything just leaves. So if glucose diffuses out of the dialysis bag, they think that there is no more glucose left within the dialysis bag. (stimulated recall interview, Day 1)

Jason challenged students to rely upon their observations to explain the movement of water, glucose, and iodine. During the lab discussion, he continually asked students to go back to their observations and find evidence to support their claims and identify molecular motion as the driving force for diffusion and osmosis. He asked “How do you know?” (Jason, Day 1). Next, Jason introduced the terms hypertonic, hypotonic, isotonic, and concentration gradient. He linked the terms to students’ observations of osmosis and diffusion during the investigation.

On Day 2, Jason implemented the *Osmobeaker* computer program (Meir, Stal, & Maruca, 2004) to challenge students to apply their knowledge of osmosis and diffusion and solve a realistic problem involving the maintenance of homeostasis between virtual representations of a red blood cell and an IV solution. Jason explained:

This will be a performance enhancement type thing in that they will actually have to use what they learned. You have cells with IV fluids and they have to manipulate the amount of dissolved solids in IV fluids so they do not damage the cell and so forth. They have to do percentages and they have to evaluate how many molecules are going inside the cell. Then there is a mystery at the end where they have to determine what the IV solution has to be in order to keep the cell alive. (stimulated recall interview, Day 2)

Jason explained that the *Osmobeaker* computer program (Meir, Stal, & Maruca, 2004) provided a clear representation of osmosis for the students by stating:

I like this lesson because you can actually see the water molecules moving through the cell membrane. The lab we did earlier you cannot see the movement of water molecules across the membrane but in this computer program lesson you can. (stimulated recall interview, Day 2)

Jason described the lesson on Day 2 as inquiry, explaining that students were to change the concentration of dissolved solid in the IV solution and predict the outcome in terms of the direction of osmosis. He explained:

The lab itself is conducive to inquiry because it has a couple of things where you have to figure out what is actually the concentration of dissolved solids inside the red blood cell and in the IV solution. So there is inquiry there and there is a lot of inquiry in figuring out what I have to have in the IV solution to keep the cell isotonic. There is a trial and error process there. So it inside the cell it puts hemoglobin and sugar and all of those things in there correctly to make sure that the cell does not get too big or too small. So they have to maintain the right concentrations inside the cell. (stimulated recall interview, Day 2)

Jason believes making connections between content and student experiences has the potential to enhance student learning and noted when talking about osmosis and diffusion, he often referenced laxatives and diarrhea to define relationships between content and human physiology. He noted:

We talk about diarrhea and about osmosis occurring in the intestine and stuff like that. A lot of the kids tell me that they never thought about anything like that occurring. I try to find experiences that students have experiences with whether it be something gross like diarrhea or something else. (pre-observation interview)

Jason was the only study participant to integrate mathematics into his teaching of osmosis and diffusion. Jason noted that his goal was for students to understand how to calculate ratios to determine the relative concentrations of dissolved solids and water in each solution. Jason challenged his students to use their calculations to predict the direction of osmosis when working with the *Osmobeaker* program (Meir, Stal, & Maruca, 2004). He explained:

Today was easy because it just so happened that both sides of the membrane had 250 molecules [molecules of dissolved solid]. But tomorrow one side will have 250 molecules and the other side will have 150 molecules so that will not be as easy to see. So they will actually have to figure ratios and not just go by the number of molecules. (stimulated recall interview, Day 2)

Once students can visualize what is actually occurring during osmosis and diffusion “then doing the manipulatives and the math and percentages is easier” (stimulated recall interview, Day 2). Jason implemented two strategies for teaching osmosis and diffusion. First, the dialysis bag lab provided an opportunity for students to explore the concepts. Second, Jason challenged students with maintaining homeostasis within a virtual red blood cell with the *Osmobeaker* computer program (Meir, Stal, & Maruca, 2004). Jason explained his purpose was to scaffold student learning beginning with the diffusion and osmosis lab on Day 1 and challenging students to apply their knowledge to solve realistic problems through the *Osmobeaker* investigation on Day 2.

Knowledge of Students' Understanding of Science

Jason identified three overarching learning goals for the dialysis tubing investigation. First, he wanted students to understand the nature of a semipermeable; the dialysis tubing membrane was semipermeable and only allowed water, iodine, and glucose to pass through it, starch molecules were too large to pass through the tubing. Second, he wanted students to understand that glucose diffused out of the tubing achieving equilibrium between the tubing and beaker solutions. Third, Jason wanted students to accurately predict the direction of osmosis. Jason noted:

I want them to understand that Brownian motion results in osmosis and diffusion. . . . I want them to learn that substances are diffusing through a membrane because of their size. I want them to learn that when we start talking about a membrane it has actual holes but the cell membrane does not have holes but proteins that act as holes. Membranes are all semipermeable so when I start and all of this is really just resource. We will begin to draw upon it later when they begin putting together their own thoughts. (stimulated recall interview, Day 1)

Jason noted students can and do learn from one another and implemented cooperative learning into his lessons on both days. He explained that teaching and

learning go together and when one student teaches a concept to another, both learn from the experience. Jason explained:

When they use the glucose test strip, they are conversing and talking about what is going on in the lab. When I am walking around I want to see them both involved in a scientific conversation or talking about what is going on. I want to see them both involved. . . . So I am getting people to help each other. I need involvement when I walk around I want to see kids involved with each other and learning from each other. (stimulated recall interview, Day 1)

Vocabulary terms were a concern for Jason throughout lessons on Days 1 and 2; he noted students might experience difficulty connecting vocabulary with concepts. The terms he referenced as concerning included: hypertonic, hypotonic, isotonic, and concentration gradient. He explained he continually searched for examples, metaphors, and analogies that would make relevant connections between vocabulary and concepts. He noted:

The kids I have struggle with the large words and complex concepts. I will say osmotic pressure and three or four of them will not even be able to spell it so they will be turned off right away. So I have to put things in a way that they can comprehend it or do the lab and so forth. (pre-observation interview)

Jason associated four potential learning difficulties with the *Osmobeaker* computer investigation including: (a) comprehension of vocabulary terms, (b) prediction of the direction of osmosis, (c) navigation of the computer program, and (d) confusion with mathematical calculations of ratios and percentages. To address his concerns, Jason engaged students with a brief review of relevant vocabulary terms from Day 1. A list of key terms and definitions (hypertonic, hypotonic, isotonic, and concentration gradient) were written on the whiteboard as a ready reference for students. Next, Jason discussed the direction of osmosis students observed during the dialysis tubing investigation to make a clear connection between the tonicity of the environment and direction of

osmosis. Jason familiarized students with the program, and provided a step-by-step explanation of the mathematics to assist students with calculations of ratios and percentages. He explained:

Well, first I wanted the students to understand how to use the control buttons on the computer so that they could click on permeable to see how many molecules there were in each compartment. The second thing is I wanted to make sure that they understood how to use the terms that we were talking about in explanations such as hypertonic, hypotonic, and isotonic. The third thing is that I wanted to make sure that they understood the math part and how to figure concentrations and how to figure percentages, ratios and stuff like that. (stimulated recall interview, Day 2)

Concerns for student learning resulted from Jason's struggles with dyslexia. He modeled effective learning strategies for his students and viewed lessons from students' perspective, Jason explained, "Usually my strategies come about from thinking about the student first" (stimulated recall interview, Day 2). He considered three factors when designing lessons: (1) investigations preceded lectures to scaffold student learning, (2) lectures are interactive and engaged students in explanations and provided examples, metaphors, computer animations, and analogies to enhance comprehension, and (3) students are challenged to draw upon their knowledge to find answers and solve problems.

Knowledge of Assessment

Jason believes that formative assessments provide important insight into student thinking and prior knowledge. He noted the importance of students' predictions in revealing their understanding of the direction of diffusion of glucose and iodine as well as the direction of osmosis for the dialysis tubing investigation. Jason challenged his students to predict outcomes for the dialysis tubing investigation and provide a rationale for their predictions. By challenging students to make and explain predictions, Jason

revealed students' prior knowledge of diffusion and osmosis and focuses students' thinking during investigations. Jason explained:

If students do not make a prediction it is harder for them to think through the process and understand what happened and what is going on. But if students made a prediction they are saying "OK I think osmosis will be in this direction. If water does move in this direction, then why does this happen?" So I think it puts students into a more analytical mind. (stimulated recall interview, Day 2)

Jason noted something as simple as student answers to questions posed during a class discussion on osmosis and diffusion can reveal students' conceptual understanding. He believes that feedback from formative assessments can effectively inform his next steps in a lesson. Jason explained:

I may ask about why water is the universal solvent because of its polarity or I might ask how water moves up through plants. Both of those questions require the kids to explain the situation through the polarity of water. (stimulated recall interview, Day 2)

Jason noted the importance of assessing student preconceptions and misconceptions prior to the start of the lesson. He initially questioned students to reveal their knowledge of osmosis and diffusion from the lab completed during the previous lesson and had planned to review the concepts of diffusion and osmosis if students' answers indicated a lack of understanding of diffusion and osmosis. Jason explained:

I was asking questions to make sure that we [the students] understood osmosis and diffusion before we started the software. If they had not done well with that I would have had to explain those two processes so that they could get it. I would have said OK, we have too much indigestible stuff in the intestine that means that water will enter the intestine. (stimulated recall interview, Day 2)

Jason noted the importance of lab analysis questions to gain insight into student thinking. He explained that the questions he asks challenge students to apply their knowledge of content. Student responses to the lab questions provided insight into

students' understanding and ability to apply their knowledge to solve novel problems related to the laboratory investigation. He explained:

When I ask post lab questions I want them to take what happened and then take it to the next level. . . . For instance, one of my post lab questions was: Why do humans have to do osmosis? What is so important about that? or Why can't the skin do osmosis freely like most cells? So they have to kind of use what we did and apply it to a different situation so they can see what is going on. (pre-observation interview)

Another means of assessing students' understanding lies within the nature of student work. Jason explained that he expected his students to show their work when calculating percentages and ratios and not simply post an answer. He indicated that he implemented this rule to gain insight into students' thinking by noting the manner in which they solved problems.

The *Osmobeaker* lab itself is conducive to inquiry because it has a couple of things where you have to figure out what is actually the concentration of dissolved solids inside the red blood cell and in the IV solution. So there is inquiry there and there is a lot of inquiry in figuring out what I have to have in the IV solution to keep the cell isotonic. There is a trial and error process there. So it inside the cell it puts hemoglobin and sugar and all of those things in there correctly to make sure that the cell does not get too big or too small. So they have to maintain the right concentrations inside the cell by manipulating the concentration of dissolved solids in the IV solution. (stimulated recall interview, Day 2)

Jason incorporated informal formative assessments into his teaching. He used students' predictions to reveal prior knowledge and students' conceptual understanding of phenomena. On Day 2, he challenged students to complete calculations determining the relative concentrations of dissolved solid within the cell and the IV solution. Jason moved through the classroom and interacted with the students to assess their understanding and determine if students were able to accurately implement mathematics. Jason explained:

I was hoping that they would get the concept of pressure and that they would know that by adding or subtracting more molecules from the IV solution that

there would be more collisions with the membrane and that could increase or decrease it [pressure within the cell]. Then in the next question, I made them actually increase the cell [water moves into the cell]. (stimulated recall interview, Day 2)

As Jason moved through the room and looked over his students' shoulders, he asked questions to determine if they understood the concepts. During the *Osmobeaker* (Meir, Stal, & Maruca, 2004) lab, Jason assessed students' understanding of osmosis by asking students to predict concentrations of dissolved solid within the IV solution which would result in an increase or a decrease within cell volume.

Jason noted formative assessments provide valuable insight into student thinking and understanding. He believes that feedback from formative assessments can effectively inform the next steps in his teaching. Jason challenged students to predict the direction of diffusion of dissolved solids (iodine and glucose) and the direction of osmosis (water movement) during the dialysis investigation and the direction of osmosis following each manipulation of dissolved solids within the virtual IV solution throughout the *Osmobeaker* computer software (Meir, Stal, & Maruca, 2004) investigation. Jason demonstrated careful observation of student work, noting students' ability to apply their understanding of osmosis and diffusion to answer analysis questions, to solve problems determining solute ratios within solutions, and accurately predict the direction of osmosis and diffusion.

Knowledge of Curriculum

Jason is well aware of curricular guidelines and noted the importance of state Course Level Expectations (CLEs) when developing curriculum and planning lessons. He explained that covering the content identified by CLEs guides his planning.

They have got to know the parts of the cell membrane, lipids, carbohydrates, and proteins. They have to know what these parts do and then how things cross the membrane. So all of the different type of membrane transport to cross the membrane and why is it important that substances are able to cross over the cell membrane. Why is it important, this is the most important of the objectives. It is hard to get to the fourth one before students get the first three. So I want them to know why do plants have to have water cross the cell membrane. Why do human beings and animal cells have to have water? (pre-observation interview)

Students in Jason's classes are not issued textbooks in the beginning of the school year; Jason noted students respond more positively when engaged with technology.

Therefore, when given the choice of purchasing textbooks or lap top computers, Jason chose the computers. A set of older textbooks are in his room for students to check out if necessary. Jason believes his students are oriented toward learning with technology. He explained:

Before I got this program we just drew pictures and it was more of a coloring type thing or picture drawing. We would do the lab. The dialysis tubing might be done later in the lesson and then ask the kids to draw what is occurring and draw the movement of water and so forth. This is much better because they can actually manipulate the numbers and see the changes and they can work their way through the process and see what has to be in the IV bag. (stimulated recall interview, Day 2)

Jason noted an understanding of osmosis and diffusion is critical for student comprehension of biological concepts taught later during the school year. When asked about the sequence of the dialysis lab and the *Osmobeaker* program (Meir, Stal, & Maruca, 2004), Jason explained that he put the dialysis tubing investigation first because he believed that students would develop a basic understanding of osmosis and diffusion and reflect upon the dialysis investigation to understand the computer lab on the following day. He explained:

I put the dialysis bag lab first where they can actually know, basically what the dialysis bag does is that it lets you know that osmosis did occur here and diffusion did occur here. Then by doing this lab they can comprehend going back to the

dialysis lab we did they can understand that there were small holes in the membrane and things were diffusing. They have something that they can actually see, a visual of what is happening when osmosis and diffusion occur. Taking these things together, they have a visualization of what is occurring. (stimulated recall interview, Day 2)

Once students can visualize what is actually occurring during osmosis and diffusion “then doing the manipulatives and the math and percentages is easier” (stimulated recall interview, Day 2).

Jason noted that students must understand the structure and function of the cell membrane and how materials enter and exit the cells to maintain homeostasis. He also explained that movement of water across a membrane was involved in other key processes essential to life on earth, such as photosynthesis and cellular respiration. Jason explained that in biology each lesson builds upon the concepts learned in previous lessons. He explained that in biology “the next lesson will build upon this one.” (pre-observation interview) Jason also noted that future biology courses will require student knowledge of osmosis and diffusion in terms of percentages of dissolved solids and ratios of solute and solvent within the cell and the surrounding solutions. He explained, “So next year when these kids take Advanced Biology when we begin doing this with molarity they will have a much better understanding because we did this with percentages and ratios” (stimulated recall interview, Day 2). Jason noted that state and district guidelines for biology support the development of the general biology curriculum. His knowledge of curriculum extends well beyond standards imposed by the state and district; he is also very aware of the sequence of instruction necessary to scaffold student learning.

Jason's PCK for Teaching Diffusion and Osmosis

Throughout his teaching, Jason demonstrated an ability to integrate the components of his teacher knowledge to develop effective and relevant learning opportunities for students. The Magnusson et al. (1999) model of PCK has been modified to illustrate Jason's PCK for teaching osmosis and diffusion (see Figure 17).

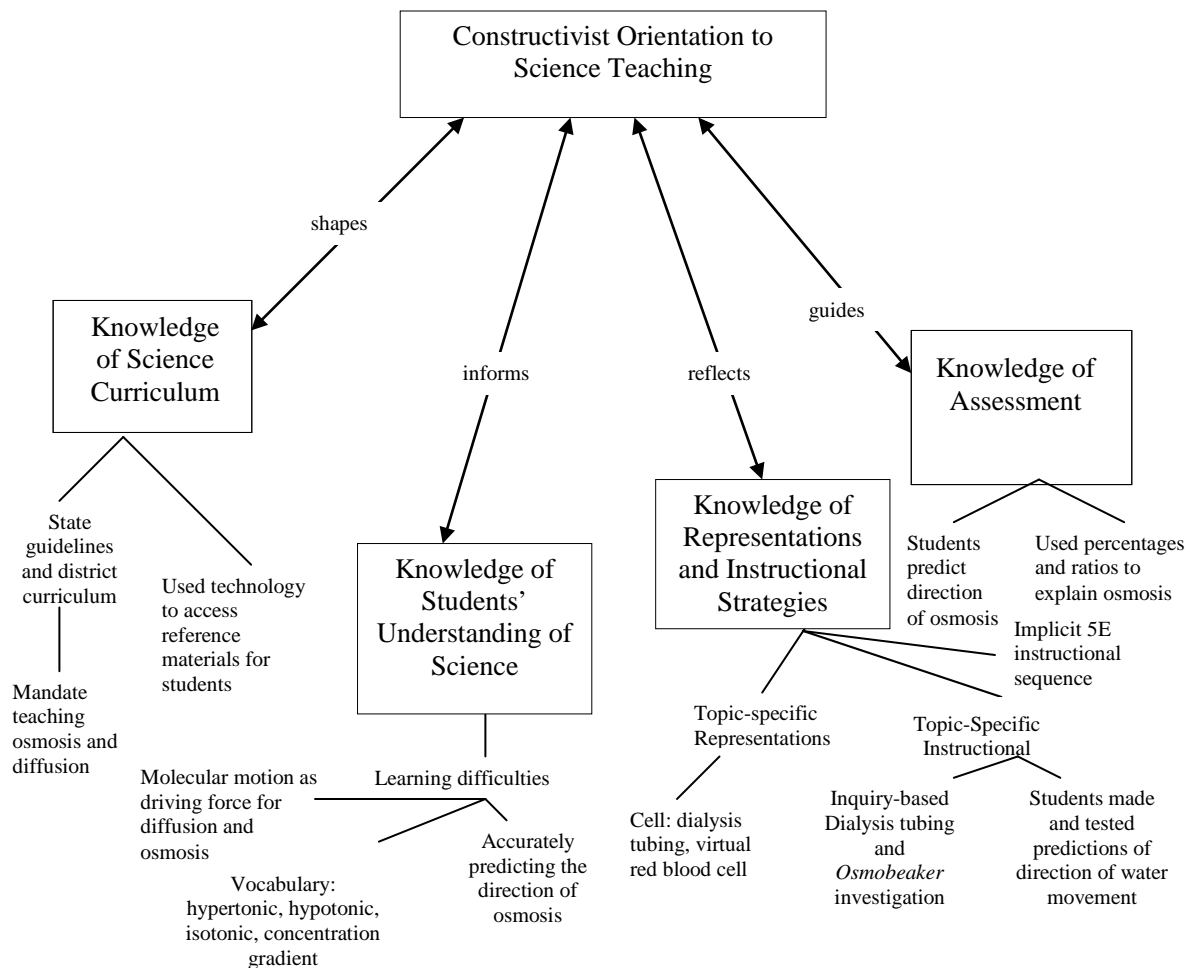


Figure 17: *Jason's topic-specific PCK*

¹⁷Note: Modified from Nature, sources, and development of pedagogical content knowledge for science teaching (p.99), by S. Magnusson, J. Krajcik, & H. Borke, 1999. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 95-132). Boston: Kluwer

Jason believes effective learning occurs when students are actively engaged in solving problems and investigating concepts. During each lesson of the observation, he engaged students in investigations of osmosis and diffusion, challenged them to make and test predictions, and required explanations to be supported with evidence. His orientation for science teaching is best described as constructivist. Jason's beliefs about teaching and learning acted as a filter in shaping the nature of representations, instructional strategies, and sequence of instruction. Jason designed lessons to build upon students' knowledge of osmosis and diffusion; he utilized the investigation as an introductory exploration of osmosis and diffusion, preparing students for the guided inquiry *Osmobeaker* (Meir, Stal, & Maruca, 2004) investigation to be completed on Day 2. Jason used representations relevant to students' prior knowledge and experience to make connections between osmosis, diffusion and students' lives.

A theme noted throughout Jason's teaching was the emphasis he placed upon making and testing predictions and problem solving. Whether he was challenging students to predict the direction of movement of water, iodine, and glucose or to calculate relative concentrations of dissolved solid, Jason was challenging his students to think critically and use their knowledge to solve realistic problems. Throughout his lessons he also relied upon formative assessments to gain insight into students' thinking and comprehension. This insight also informed his next steps within the lesson.

Jason understood the potential learning difficulties students were likely to face with this content and sequenced the lessons to support student learning. Students were challenged to apply the knowledge gained during the investigation and lecture/discussion on Day 1 to solve the problems posed by the *Osmobeaker* program (Meir, Stal, &

Maruca, 2004) on Day 2. By implementing the *Osmobeaker* program (Meir, Stal, & Maruca, 2004), he used a constructivist instructional approach to challenge his students to apply their knowledge of osmosis and diffusion to maintain homeostasis (equilibrium) between a red blood cell and an IV infusion. A model of Jason's PCK for teaching diffusion and osmosis is shown in Figure 18.

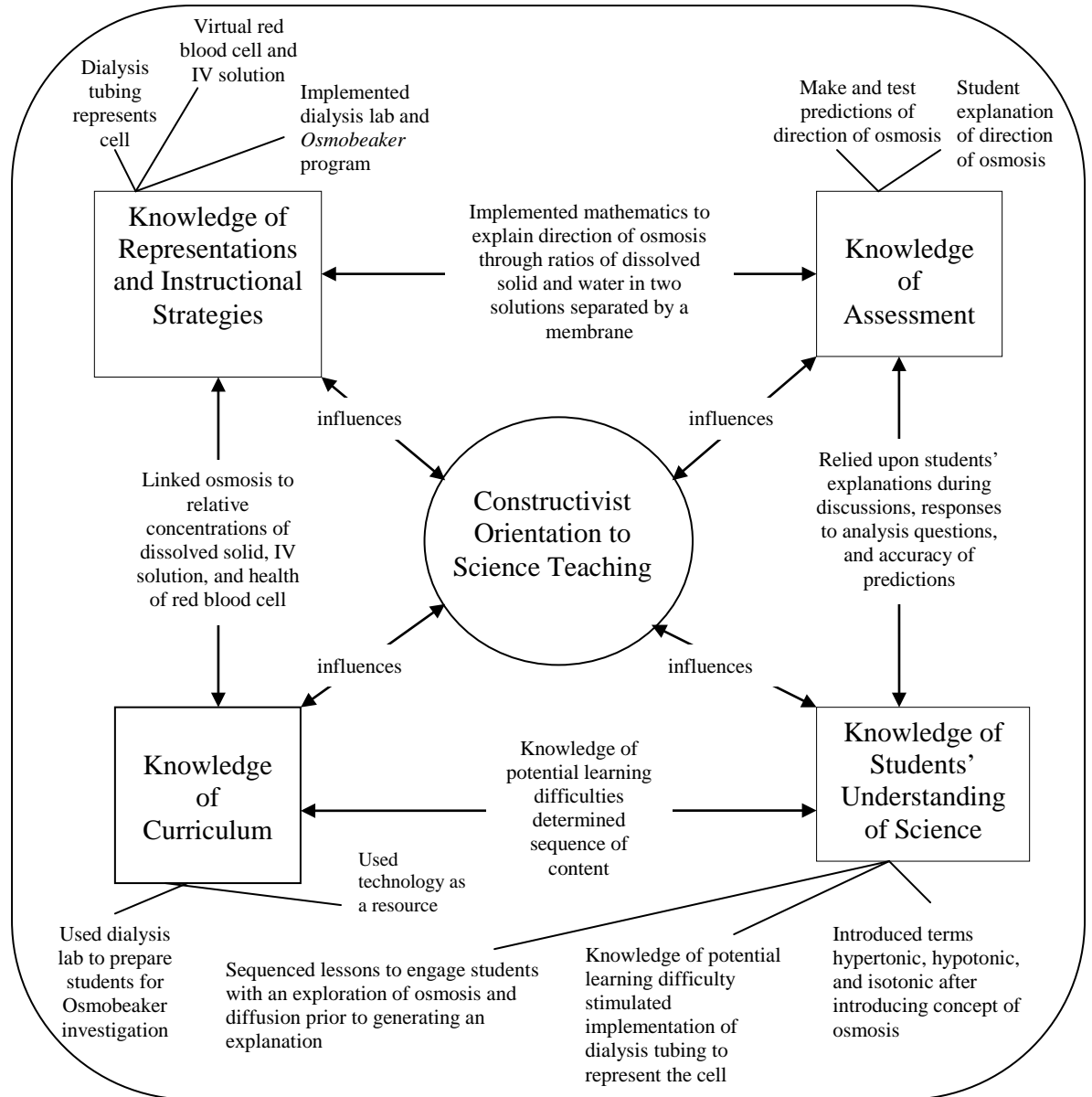


Figure 18: Integration of the components of Jason's PCK

Jason's PCK for teaching diffusion and osmosis, shown in Figure 18, represents the integration of PCK components creating teacher knowledge specific for teaching diffusion and osmosis. There are four important features to note within this representation. First, Jason's orientation to science teaching is placed within center of the model indicating his orientation acts as a lens through which the four components of Jason's PCK were viewed. Second, Jason drew heavily upon all four components of his PCK to plan and teach his lessons. Third, connecting arrows between components indicate the highly integrated nature of this knowledge. It is difficult to distinguish between the components which Jason drew upon to design representations, instructional strategies, instructional sequences, and assessments most effective for teaching osmosis and diffusion. Fourth, connecting statements between components provide insight into Jason's integration of knowledge for teaching diffusion and osmosis.

Jason drew heavily upon his knowledge of students as learners when designing and teaching lessons. The representations, strategies, and assessments reflected his goals for student learning and his knowledge of potential learning difficulties. He embedded formative assessments into his lessons, using students' predictions and analyses to inform next steps in his lessons. Jason's knowledge of curriculum and curricular resources informed his implementation of the dialysis tubing and *Osmobeaker* (Meir, Stal, & Maruca, 2004) investigation. Jason integrated all PCK components when teaching diffusion and osmosis.

Content Representation

In Table 21, a Content Representation (CoRe) (Loughran, 2006) illustrates Jason's knowledge of teaching. The components of PCK are represented within the

context of the CoRe and specific examples of instructional strategies and representations, assessments, potential student difficulties, and curricular considerations are included.

When reading the CoRe, it is important to read individual columns (e.g. Big Idea A) from the top to the bottom vertically. The columns extend beyond a single page.

Table 21. *Content representation for Jason*²¹

Content Representation (CoRe)			
Considerations	Big Idea A	Big Idea B	Big Idea C
	Plasma membranes are semipermeable.	Water will diffuse across a cell membrane from higher concentration to a lower concentration.	Changes in the environment of a cell will result in changes in the direction of osmosis.
Identify the learning goals for students within this lesson?	<ul style="list-style-type: none"> Plant and animal cells are surrounded by a semipermeable membrane which only allows some substances to enter the cell. Cell membranes physically isolate the cell from the environment. The membrane is constructed from a phospholipid bilayer. Specialized proteins act as channels to allow water to enter and leave the cell. 	<ul style="list-style-type: none"> Osmosis is the diffusion of water across a semipermeable membrane The direction of osmosis is determined by the concentration gradient. 	<ul style="list-style-type: none"> During osmosis, water will flow toward the solution with the highest concentration of dissolved solid or solute and the lowest concentration of water. Percentages of dissolved solid or solute within a solution can be used to calculate the percentage of water within the solution. Changes in the dissolved solid within an IV solution will change the direction of osmosis within body cells.
Why is it important for students to know this content? <i>[Knowledge of curriculum]</i>	<ul style="list-style-type: none"> All cells have a cell membrane which acts as a barrier to the environment. All living things require water and there must be a way for water to enter and leave the cell. 	<ul style="list-style-type: none"> Osmosis is the diffusion of water across a cell membrane. Cell membranes are hydrophobic with proteins acting as channels for the passage of water. All substances will diffuse from areas of high concentration to areas of lower concentration. 	<ul style="list-style-type: none"> Students can calculate the molarity of each solution to predict the direction of water movement. All living cells must regulate the movement of water into and out of the cell. Molecular motion is the driving force for diffusion and osmosis. Osmosis is involved in other life processes such as photosynthesis and cellular respiration.

<p>Identify potential student difficulties and limitations associated with teaching this idea. <i>[Knowledge of students as learners]</i></p>	<p>Students will have difficulty understanding:</p> <ul style="list-style-type: none"> • vocabulary terms and definitions. • the function of channel proteins within the cell membrane. 	<p>Students will have difficulty with:</p> <ul style="list-style-type: none"> • predicting the direction of osmosis. • determining the direction of water movement during osmosis during laboratory investigations. • explaining the direction of diffusion. 	<p>Students will have difficulty with:</p> <ul style="list-style-type: none"> • calculating ratios to determine the relative concentration of solute in each solution. • using ratios of dissolved solid within two solutions separated by a semipermeable membrane to identify the relative concentration of water. • using ratios to identify the direction of osmosis. • calculating the percentage of water from the percentage of solute. • manipulating the <i>Osmobeaker</i> computer lab program.
<p>Identify knowledge of students' thinking which influenced the teaching of this idea. <i>[Knowledge of students as learners]</i></p>	<ul style="list-style-type: none"> • Students may have misconceptions concerning the structure and function of cell membranes. 	<ul style="list-style-type: none"> • Students may have difficulty understanding the complex concepts of diffusion and osmosis in terms of the particulate nature of matter and molecular motion. 	<ul style="list-style-type: none"> • Students learn effectively from other students through collaboration. • Models make complex concepts easier for students to understand. • Students can use models to make and test predictions.
<p>Teaching strategies and representations implemented and particular reasons for using these strategies to engage students with this idea. <i>[Knowledge of instructional strategies and representations]</i></p>	<ul style="list-style-type: none"> • The dialysis tubing is an effective cell model and can be used by students to investigate the nature of a semipermeable membrane. • Computer graphics and animations can support students' understanding of complex concepts. 	<ul style="list-style-type: none"> • Dialysis tubing can be used as a learning tool for students to make and test predictions of the direction of water movement during osmosis. • The diffusion of iodine into the dialysis bag is noted when the starch solution within the bag changes color from translucent white to dark blue or black 	<ul style="list-style-type: none"> • Students can test for the presence of glucose during the dialysis tubing investigation to emphasize the diffusion along a concentration gradient. • The <i>Osmobeaker</i> computer software provides an interactive example of osmosis. • Strong connections can be made between computer programs and real-world scenarios.
<p>Identify ways of ascertaining that students' concepts taught. <i>[Knowledge of Assessment]</i></p>	<ul style="list-style-type: none"> • Student understanding can be determined by the nature of their responses to questions posed before and during investigations. 	<ul style="list-style-type: none"> • Student responses to questions about the dialysis laboratory investigation provide insight into student thinking. 	<ul style="list-style-type: none"> • Students' predictions of changes before instruction reveal students' prior knowledge of diffusion and osmosis.

-
- If student answers are assessed and returned by the following class period, discussions are more meaningful because the information is clearer in student minds
 - Critical thinking questions require students to think deeply about the laboratory investigation. Students' answers reveal their conceptual understanding of phenomena.
 - Students use arrows to indicate the direction of osmosis and diffusion in diagrams included in the dialysis lab analysis questions reveals students' thinking and conceptual understanding.
 - Students predictions during the *Osmobeaker* computer lab reveal students' conceptual understanding of osmosis.
 - Student calculations of relative concentrations indicate understanding of mathematics and the movement of water along its concentration gradient.
 - Student responses to questions about the relative concentrations of dissolved solid with the IV solution and the human blood cell reveal student understanding about osmosis, diffusion, and concentration gradient.
 - The appropriate use of terms "talking like a scientist" indicates student understanding of vocabulary and concepts related to osmosis and diffusion.
-

The content representation (CoRe) provides an overview of Jason's teaching in terms of the implementation of each component of PCK and reveals important insight into his teaching.

²¹Note: Modified from *Understanding and developing science teachers' pedagogical content knowledge*, by J. Loughran, A. Berry, and P. Mulhall, 2006, p. 28. Rotterdam: Sense Publishers.

Kacy's Case Profile

Kacy's Vignette: Making and Testing Predictions

“Okay guys, today is going to be a very busy day. We have a lot to do and I want everyone to be focused!” Kacy stated as students walked into her classroom.

“So I guess we will be doing a lab today?” a student asks as she places her books under her desk.

“You bet! Be on your toes, we have a lot to do!” Kacy answers emphatically.

“Okay, first I want you to listen to directions for the lab we are going to set up today; this is the transport lab inquiry” Kacy informs her students as she passes out the lab sheets. “Follow along on your lab sheets as I review the directions,” she tells the students.

“Okay, Step 1: pick up the equipment from the equipment cart in the front of the room. Step 2: pour 300 ml of the iodine solution into the 750 ml beaker,” Kacy states. She holds up a small sandwich bag as she lists the next step, “Pour 50 ml of the starch solution into the baggie; the starch solution, baggie, and graduated cylinder are all at your lab stations,” Kacy states as she focuses on her students, making sure that they are listening to her instructions.

“Should we write down our observations?” a student asks.

“Good point, Grace, make careful observations and record your data during the investigation,” Kacy responds.

“Well, what are you going to do next?” Kacy asks the students as they pour over the directions for the lab.

“I think we should pour the iodine solution into the beaker,” a student responds.

“Hey, when do we put the baggie in the beaker solution?” another student asks.

“We want to put the baggie with the starch solution in it into the beaker containing the iodine solution,” a student responds in the back of the room responds.

“You guys are great, that is what I want you to do” Kacy reminds her students.

“But what are you going to do before you place your baggie in the beaker,” Kacy asks the students.

“I know! I know this!” shouts a student. “We predict what is going to happen to the solution in the beaker and the solution in the baggie,” she continues.

“Wow, I am impressed,” Kacy responds as she looks around the room.

“Oh yeah, like we never make predictions in this class!” a student states rolling his eyes.

“Hey, I like making predictions; it is fun to see how things turn out and look, we don’t have to make up a table for our observations, Ms. G. made it for us,” another student responds.

“Now, I want you to think about the baggie and remember there is a unique solution inside the baggie that is not found in the beaker, right?” Kacy asks the students.

“Hey, the baggie kind of like a cell, isn’t it?” One student asks.

“Yeah, and the baggie is like a cell membrane that contains a starch solution instead of, like a cell containing cytoplasm, right?” Another student states.

“This is great, you guys get the idea that the baggie is like a cell in this lab. Good job!” Kacy adds.

“Hey guys, your lab team is going to predict what will happen to both solutions; the solution in the baggie and in the beaker,” Kacy tells the class. “I want you to think

about these solutions, but I want you to watch this first,” she tells the class. “Remember that iodine is an indicator for starch,” Kacy reminds the class. “When you add iodine to starch, there is a color change,” she tells the class as she pours a small quantity of iodine into test tube containing a starch solution.

“Wow, it changed. Like it changed from white to black,” a student comments as he watches Kacy.

“That is right, so I want you to think about this, the starch is in a baggie and the iodine is in the beaker, so talk to your row partner and make a prediction about what will happen when you place the baggie into the beaker of iodine and water,” Kacy states. There is a muted buzz in the room as students turn to talk to their row partners and decide on a prediction for the investigation.

“Okay guys, once you have settled on a prediction, what should you do?” Kacy asks the students.

“Well, I think we should write it down on our lab sheet,” a student responds.

“Good, after each team has made and recorded a prediction, how will you test your prediction?” Kacy asks the class.

“I know, I know!” A student responds waving her hand wildly. “Like, we to see what happens after the baggie is in the iodine solution in the beaker,” she tells the class.

“Yeah, then we can keep an eye on it and look for changes in the baggie and beaker,” another student tells the class.

“Okay, sounds good. Now go to your lab tables and get going. Remember we will be doing lots other things during class, so you must be quick,” Kacy reminds the students.

The students quickly move to their lab tables and for moment there is a flurry of activity. As students settle into their lab groups, Kacy moves around the room and stops

to talk with and ask questions of each lab group. After setting up the lab, students place the beakers in the middle of their lab tables and quickly return to their seats.

“I want you to go to your lab tables and look at your baggie lab set ups; look carefully and write your observations down and think about your prediction,” Kacy explains after a brief discussion during which students shared their predictions.

“Hey, the solution in the baggie is like, dark,” a student proclaims as she studies the beaker with her lab group.

“We were right,” another student claimed as he rotates the beaker in his fingers.

“Well, what do you see?” Kacy asks. “How has your lab set up changed and why has it changed?” She asks.

“It was the iodine,” a student shouts. “The iodine went into the baggie,” the student continues.

“Well good,” Kacy responds. “What about the rest of you? Do you agree?” she asks as students continue to study their beakers.

“Yeah, the iodine must have gone into the baggie,” another student states as she looks to her lab partners for their approval.

“Well, I have a question for you, what happened to the iodine solution in the beaker?” Kacy asks.

“It did not change,” several students respond in unison.

“Okay, so what does that tell you?” Kacy asks.

“I know, I know!” A student in the back shouts waving her hand in the air. “The iodine went into the baggie but the starch did not come out of the baggie,” she continued.

“Interesting, what evidence do you have to support that claim?” Kacy asks as she looks around the room.

“Well, our group thinks iodine diffused into the baggie and made the starch turn black, the baggie looks bigger than it did when we put it into the beaker, the starch did not come out of the baggie because the only color change was inside the baggie,” the spokesman for the group tells the class.

“Yeah, and our baggie looked bigger too, like water and iodine went into the baggie,” a student from another team observed.

“Our baggie seemed to be bigger too,” another student claims.

“Well good, now I would like you to think about this, why did the water and iodine enter the baggie?” Kacy asks the students.

“To help you find an answer to that question, we are going to look at lettuce leaves,” Kacy tells the students.

Background and Context

Kacy is a veteran biology teacher with seven years of teaching experience at Rollins High School. Her teaching experience includes tenth grade general biology and honors biology. Rollins High School is located within a mid-western community with a population of approximately 75,000 and includes grades 10-12 with an average student to teacher ratio of 24/1, above the state student to teacher ratio of 18/1 (DESE, 2008).

Rollins is on a block schedule with 90 minute classes meeting on alternate days.

Kacy’s classroom is bright, clean with wooden cabinets lining the white walls. The center of the classroom contains a traditional arrangement of student desks in five rows of six desks each facing a whiteboard and Smart Board in the front of the

classroom. There are six laboratory tables the back and outside walls of the classroom. Each laboratory table includes seating for four students and is equipped with a sink, hot and cold water, and gas jets. During lessons, students transition from their desks following whole class lecture and discussion to the laboratory tables for the completion of investigations or activities during lessons.

Kacy is the most senior member of a Biology Professional Learning Team (PLT) at Rollins High School. During weekly meetings, the PLT collaborates to develop learning objectives and curricular materials for each unit. Curricular materials include guided lecture notes, laboratory investigations, activities, worksheets, as well as formative and summative assessments all of which are aligned to the state Course Level Examination (CLE), and the district biology science curriculum.

Orientation to science teaching

I describe Kacy's science teaching orientation in terms of these five dimensions: (a) goals and purposes of science education, (b) perception of teacher role, (c) perception of student role, (d) ideal images of teaching, and (e) view of science as a discipline.

Goals and purposes of instruction. Kacy's overarching goal for teaching biology is to actively engage students with explorations of phenomena and, through their experiences and observations, construct their knowledge of biology. She explained goals for student learning shape her lessons and she strives to align all demonstrations, activities, investigations, lectures, and discussions to the goals and make expectations for student learning crystal clear. She noted, "I like to run this classroom so that it is like a well oiled machine" (stimulated recall interview, Day 2). Kacy indicated she included

objectives for both lessons along with key vocabulary terms and guided note pages in student packets distributed on Day 1. She explained:

When the kids come in we all know what we need to do. I do not want the learning process to be a mystery to them. . . . I want them to know what we are doing and why we are doing it. And from that point I like them to be engaged as much as possible. (stimulated recall interview, Day 2)

Kacy identified five specific learning goals for lessons on Days 1 and 2. She noted a specific sequence for implementing the goals to scaffold students as they construct their knowledge of diffusion and osmosis during the lessons. She noted:

There are five objectives that we are working on in our progression and those are: explain the purposes of cellular transport; define passive transport as a process; describe how diffusion occurs and its importance in cellular activities; describe how osmosis occurs and its importance in cellular activities; and predict the direction of diffusion through a membrane when given an example. (pre-observation interview)

The overarching goal for the lessons on Day 1 and 2 was to facilitate students' conceptual understanding of the processes of osmosis and diffusion by investigating factors that drive osmosis and diffusion. One of the ways in which Kacy strives to achieve her goals for students' learning is by incorporating cooperative learning into her teaching and clustering students who she believes will be supportive of one another and work well together. She explains: I have picked the student seating chart so that everybody has someone who can support them (stimulated recall interview, Day 2).

She planned learning opportunities to engage students in the constructing their knowledge of diffusion and osmosis and how and why these processes occur in both living and nonliving systems. She explained, "What I mean is building a framework in which I create steps in the learning process for the students and that I do not expect students to be at "A" work immediately" (pre-observation interview). Kacy consistently

challenged students to apply their knowledge of osmosis and diffusion by making and testing predictions for outcomes of teacher demonstrations and student investigations.

She explained:

You just do not explain cellular transport, you have to scaffold their ability to explain cellular transport so by providing lots of different scenarios even though we are dealing with the same concept over and over and over again. What they are doing is practicing applying that to understand the concept better. (pre-observation interview)

She emphasized the sequence of demonstrations and investigations within the context of each lesson and noted her purpose was to support students' learning and make smooth and logical transitions between concepts. She explained:

I have to think about the order of activities. What order of these activities makes the most sense to get them from concept to concept as well as what transitions are going to make the most sense? So that everything moves smoothly and we can go from this activity to this activity and then go to our lab tables and then go back and sit down. (stimulated recall interview, Day 2)

Kacy's overarching purpose in science teaching is to actively engage students in learning about science and to make relevant connections between learning objectives and representations, demonstrations, activities, and investigations in her lessons. Kacy explained she wants her students to construct their knowledge of biology. She noted her colleagues within the context of a Professional Learning Team (PLT) support the goals and purposes for teaching biology.

I am lucky enough to work with a professional learning team. There is a group of biology teachers and we all agree on common biology goals and objectives of what should be taught. . . . So those were the places that I started off with first. What were my objectives and what does that final assessment look like. (pre-observation interview)

Within the context of each lesson, Kacy included opportunities for students to practice applying their knowledge of osmosis and diffusion and make and test predictions

for each scenario. Her goal is to engage students in investigating concepts and constructing their knowledge of biology.

Perception of teacher role. Kacy believes her teacher role is to act as a facilitator of student learning and reinforce students' learning with demonstrations and investigations in which students practice applying their knowledge of osmosis and diffusion to different scenarios. She explained, "this is still reinforcement; they still need that practice, and is still important for them (pre-observation interview). She focuses on learning targets to guide the sequence of instruction, the choice of representations and instructional strategies, and the assessment of student progress. Kacy explained:

I think that my role is to know what I am teaching, to know what my students are going to be able to do and what it is that they are supposed to know in the context of our content [biology curriculum]. So it is my job to know what those expectations are and then to provide the means for my students to meet those learning targets. (stimulated recall interview, Day 2)

She noted her perception of her role as a teacher has changed over time as she gained teaching experience. She explained:

My real learning began when I started teaching; I learned from colleagues, I have learned from education research, and I have learned from reading textbooks and then putting it in a way that I feel will make the most sense to my students. (pre-observation interview)

The question she continually asked herself to guide her thinking throughout this planning process is "What do I want my students to know and be able to do?" (stimulated recall interview, Day 2). Thus, instead of focusing on what she will do as the teacher, her focus is on the learning objectives for her students and what students will be doing to learn content. Kacy explained:

Before I begin planning my unit I have my learning targets right there and I am thinking about what I am addressing each day. I go back and forth to decide the sequence of my instruction, what will my students do first and second each day.

First of all, I set my learning targets for each day. From there my big question is “What are my students going to do to learn this?” So rather than asking: “What am I going to do?” I ask what my students are going to do to learn this. (stimulated recall interview, Day 2)

Because of her experience in the classroom, Kacy places a greater emphasis on student-active strategies and a decreasing emphasis on teacher-active strategies; she understands the importance of actively engaging students with learning. She explained:

I always ask myself when I am making a lesson, ‘What am I doing?’ and ‘What are the students doing?’ Because it has to be them doing it, it is not about me standing up there and delivering. It is about them grappling with it and can they make sense of it? (pre-observation interview)

Kacy uses interactive lectures as a way to draw out students’ ideas. Kacy explained she initially engages students in explorations of phenomena, next she engages students with interactive lectures to share their predictions and develop explanations based upon students’ experience with the phenomena. Her goal is to draw students into a discussion of their experiences and guide students to “focus on what the concepts are and what they mean instead of just writing down everything that is said in class” (pre-observation interview). Kacy’s goal is to increase student engagement with investigations as well as teacher and student demonstrations; thus, expanding opportunities for students to explore concepts and apply their knowledge to new challenges. She believes students should be active participants in learning and by designing learning opportunities in which students are engaged in doing science; she is addressing the wide range of learning preferences held by her students. She explained:

The idea of it is that in the handling and the doing, the students learn through the actual physical activity. So I try to provide many avenues in different ways for them to learn so that I can hit some of those visual learners, so I can hit some of the listeners [auditory learners], so I can hit the kinesthetic learners and hopefully help them. (pre-observation interview)

Cooperative learning is a strategy Kacy has implemented into her teaching. She believes as students work together they will actually learn from one another. She carefully designs seating charts to cluster students she believes will work together effectively as row partners and lab groups to support collaboration. She explained:

I also use that partnering so that I can interact with them and I can walk around and interact with the students to see how they are understanding the concepts. I can talk to that student one-on-one and I can talk to that student and check the understanding of that student or ask them where they are and what they understand and determine where I can clarify things for them. (stimulated recall interview, Day 2)

Kacy emphasized the importance of the progression of student learning and explained she supports students by designing investigations which support learning by encouraging students to build upon their knowledge and construct understanding. Connections between lessons were identified as very important and Kacy noted “I wanted to string them [concepts] all together” (stimulated recall interview, Day 2).

Beyond teaching content, Kacy believes she has a responsibility to be a role model for her students. Throughout her interactions with students, she consistently models what it means to be a good citizen, to be interested in learning, and to treat others with consideration and respect. She noted: “The other is to be a model of what a good citizen learner is so that they can see someone who cares about them and who cares about their learning and about them as individuals also” (stimulated recall interview, Day 2).

Kacy noted that her role as a teacher is that of a facilitator focused on actively engaging her students in learning by with meaningful and relevant learning opportunities which support lesson learning objectives. Within the context of her lessons, she challenges students to think critically to make and test predictions about demonstrations and laboratory investigations and reference their observations as evidence in

explanations. She also models the attributes of a good citizen learner and caring adult for her students to support understanding of positive adult behaviors and the attributes of life long learning.

Perception of student role. Kacy expects students to come to class prepared to learn. She indicated students should put forth their best effort and defined her perception of the students' role in learning by stating, "The students' role is to come to school and be ready to learn. . . . That is what their role is, to be open to the learning, to participate in their own learning, and to try their hardest" (stimulated recall interview, Day 2). She reported she expects students to be good citizen learners and show respect for the ideas of others when working together. She explained, "I want them to work with different students and I want to get them to know one other as a class. So I pick different ways to divide the students into groups" (stimulated recall interview, Day 2).

Kacy designs her lessons to engage students with investigations and demonstrations and expects her students to transition smoothly and rapidly from one activity to another. She continually reminds students of her expectation that they will be on task and transition quickly during the lesson. She explained: "I want to make sure that they flow with each other" (stimulated recall interview, Day 2).

Kacy's perception of the students' role is that students must be active participants and take responsibility for their own learning. She identified three expectations for students: (1) students will do their best work, (2) students will come to class prepared to learn, and (3) students will be responsible citizen learners in her classroom. Kacy defined responsible citizen learners as students who are on task, working hard, and collaborating with peers in a respectful and responsible manner.

Ideal images of teaching. Kacy' ideal image of teaching is focused on engaging students in learning. She noted to be effective, she must first identify the learning goals for the lesson and second ask herself what the students will do to learn the concepts. She did not perceive passive learning as an effective way to engage students because passive learners are sitting quietly in their seats listening rather than doing science. Kacy asks, "Are my students in their desks for the full ninety minutes or have I designed activities to engage the students and help them learn the concept?" (stimulated recall interview, Day 2). She believes a dynamic and effective learning environment is created when students are active participants. Kacy explained: "It is important that I have varied the activities because no one can stay engaged if they are in their seats for a full ninety minutes. What am I going to do to make sure that that is not the case?" (stimulated recall interview, Day 2).

Kacy noted the sequence of learning opportunities is an important influence on students' learning; she initially engages students in an exploration of a concept before focusing on an explanation. She explained learning opportunities should be designed to build upon one another, challenge students to apply their knowledge, and find answers to questions. Designing lessons to scaffold learning for students is a critical aspect for taking students' understanding from concrete to abstract. Kacy explained:

There are steps in that progression of learning so it is my job to figure out how to get students from point A to point B. So I need to build steps along the way to get them to step B. That is what I mean by scaffolding. (stimulated recall interview, Day 2)

Kacy's ideal images of teaching involves creating a learning environment in which learning objectives are identified, expectations for students are clear, and learning is supported with demonstrations, activities, and investigations specifically designed to

scaffold students' conceptual understanding as they move from a concrete to an abstract comprehension and apply their knowledge to find answers for new questions. When planning, Kacy's focus is on what her students will be doing to learn new concepts and the sequence of instructional activities to best support students' learning.

View of science as a discipline. The instructional sequence implemented into Kacy's lessons indicate her perception of science is as a way of knowing predicated upon knowledge gained through investigations into the natural world with claims and conclusions supported with evidence. During both days of the observation, students were challenged to make and test predictions about the direction of osmosis and/or diffusion in a series of demonstrations and investigations. Students were challenged to rely upon evidence from their investigation to support their explanations. Kacy explained:

The use of predictions is helpful in that in that they have to grapple with that and make their predictions. You noticed that when they were asked about their predictions they continued to ask questions. I know that about them and I know that I am going to hook them in if I ask them questions and start them into thinking. (stimulated recall interview, Day 2)

By consistently challenging students to make and test predictions, Kacy presented science as a means of finding answers to questions and supporting conclusions with evidence. She engaged students in investigations with uncertain outcomes rather than a body of certain knowledge presented as facts to be memorized. By challenging her students to make and test predictions she helped them to perceive scientific knowledge as uncertain, developed through investigation, and supported with evidence. Knowledge is presented as tentative in that students in Kacy's class are continually challenged to reveal their thinking, support claims and conclusions with evidence, and consider the validity of alternative explanations.

Summary of Kacy's orientation to science teaching. Kacy noted her experience teaching tenth grade biology in a large suburban high school, serving as a senior member of a professional learning team of biology teachers, and working with a professional development program focused on assessment for learning informed her orientation to science teaching. Kacy noted her collaboration with colleagues through the professional learning team stimulated reflection on her practice and the correlation between her teaching and students' learning. She identified her role as that of a facilitator actively engaging students with explorations of phenomena and generating explanations based upon students' observations and data from investigations. Figure 19 shows the sources of Kacy's orientation to science teaching.

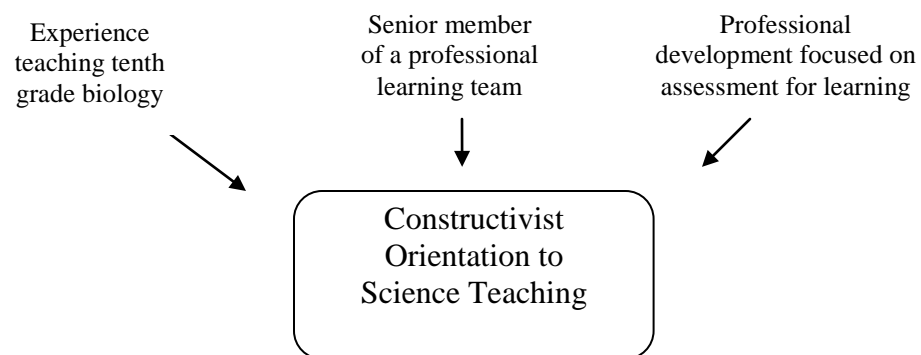


Figure 19: *Sources which informed Kacy's orientation to science teaching*

I describe Kacy as demonstrating a constructivist orientation to science teaching. First, Kacy implemented an implicit the 5E instructional model (Bybee, 1997) instructional sequence. Students were challenged to explore diffusion and osmosis before the concepts were formally introduced or explained. Thus, Kacy presented science as a way of knowing in which knowledge is gained through investigations and validated with evidence. Second, students were challenged to make and test predictions with each investigation. Students were also given an opportunity to rethink their initial predictions

within the context of new knowledge. Through her instructional sequence, Kacy emphasized the importance of student investigations of phenomena, evidence to support explanations, and supported students as they drew upon their experiences to construct their knowledge of science from their experiences. Third, during interactive lectures, Kacy engaged students in a discussion of their observations to develop an explanation for the direction of osmosis supported with evidence. Hence, Kacy designed her instruction to engage students in explorations and interactive lectures during which they reflected upon their experiences to make sense of new ideas about osmosis in cells and tissues.

Lesson Plan

Kacy's lesson plans were very thorough; in her plans, as in her teaching, she consistently made connections between lesson activities and one or more of the lesson objectives and estimated the length of time to be spent on each lesson activity. It is evident that she considers every aspect of the lesson carefully in terms of the learning goals addressed, instructional sequence, formative and formative assessments, student and teacher actions, and all within the context of the lesson time frame.

On Day 1, Kacy's lesson (See Table 22) began with an investigation into diffusion during which drops of food dye were placed in a beaker of water. Kacy asked students to predict changes likely to take place in the mixture; predictions would be tested 48 hours later during the following lesson. Next, Kacy engaged students in an investigation of osmosis and diffusion involving a baggie containing a starch solution placed in a beaker containing iodine and distilled water and challenged students to predict potential changes in the baggie and beaker solutions. A discussion lasting approximately 15 minutes followed during which students shared their predictions for both the diffusion

demonstration and the baggie investigation. Next students checked their baggie [transport] lab set ups to test their predictions. Kacy engaged students with an interactive PowerPoint lecture to discuss students' predictions and observations to generate explanations. Students worked with lab partners to complete analysis questions discussed at the close of the lesson; Kacy moved through the classroom interacting with students to gauge their understanding and redirect their thinking. An overview of Kacy's lesson plans for Day 1 is shown in Table 22.

Table 22. *Kacy's lesson plan for Day 1*

	Activity		Description
Day 1	Diffusion demonstration	Engage	Teacher: <ul style="list-style-type: none"> • Focuses students' attention on a representation of diffusion (drops of food dye are placed in a beaker of water) Students: <ul style="list-style-type: none"> • Predict changes in food dye and water to be tested during the following lesson
	Passive transport lab-investigating osmosis and diffusion	Explore	Teacher: <ul style="list-style-type: none"> • Facilitates baggie investigation into osmosis and diffusion Students: <ul style="list-style-type: none"> • Baggie containing a starch solution is placed in a solution of iodine and distilled water • Make predictions concerning direction of osmosis and diffusion of iodine
	Students share their predictions during a teacher led discussion	Explore	Teacher: <ul style="list-style-type: none"> • Conducts discussion focused on student predictions for osmosis and diffusion in baggie lab Students: <ul style="list-style-type: none"> • Share predictions and knowledge of diffusion and osmosis
	Students observe baggie and test predictions	Explain	Students: <ul style="list-style-type: none"> • Observe baggies to test predictions about direction of osmosis in baggie transport lab • Collaborate with team members to develop explanation for lab results • Complete lab analysis questions
	Students take guided notes during whole class discussion	Explain	Teacher: <ul style="list-style-type: none"> • Conducts whole class discussion • Uses PowerPoint with computer animations to illustrate osmosis and diffusion Students: <ul style="list-style-type: none"> • Share outcome of baggie lab in light of their predictions • Develop explanations for their observations

An overview of Kacy’s lesson for Day 2 is shown in Table 23. Day 2 of the observation followed a pattern similar to that of Day 1.

Table 23. *Kacy’s lesson plan for Day 2*

	Activity		Description
Day 2	Students predict direction of osmosis in decalcified eggs	Engage	Teacher: <ul style="list-style-type: none"> • Challenged students to test predictions of diffusion [food dye and water observation] • Engages students with decalcified eggs placed in corn syrup for 24 hours Students: <ul style="list-style-type: none"> • Make and test predictions of changes in decalcified eggs placed in corn syrup
	Whole class discussion	Explain	Teacher: <ul style="list-style-type: none"> • Leads class discussion Students: <ul style="list-style-type: none"> • Share predictions of decalcified eggs in corn syrup • Students use observations and knowledge of osmosis to explain changes observed in decalcified egg in corn syrup
	Students observe lettuce leaves in three different environments	Extend	Teacher: <ul style="list-style-type: none"> • Facilitates observation of lettuce leaves placed in distilled water, a concentrated saline solution, or on in the air Students: <ul style="list-style-type: none"> • Make and test predictions for lettuce leaf within each environment • Apply knowledge of osmosis to explain changes in lettuce leaves
	Students work independently on lettuce leaf analysis questions	Evaluate	Teacher: <ul style="list-style-type: none"> • Guide students’ thinking during completion of lab analysis questions Students: <ul style="list-style-type: none"> • Submit analysis questions for review

After observing changes in the food dye and water model from Day 1, Kacy challenged students to predict potential changes in decalcified eggs following placement in corn syrup for 24 hours. Predictions were tested when students observed the eggs as Kacy moved through the classroom. The egg demonstration was followed by a 15 minute interactive PowerPoint lecture. During the lecture, students drew upon their understanding of osmosis to draw arrows indicating the direction of water movement

within a diagram of a decalcified egg in different solutions. Students generated explanations for the direction of osmosis based upon their observations. Following the interactive lecture, students made and tested predictions of changes in lettuce leaves after remaining in distilled water, a saline solution, and on a paper towel in the air for 24 hours. At the close of the lesson, students collaborated with peers to respond to analysis questions accompanying each investigation. While students worked, Kacy moved throughout the room and observed students' progress.

In the following section I describe the components of Kacy's teacher knowledge including: knowledge of instructional strategies, knowledge of students as learners, knowledge of science curriculum, and knowledge of assessment.

Knowledge of Representations and Instructional Strategies

Kacy's sequence of instruction in both lessons was similar to that of the 5E instructional model (Bybee 1997) in that students initially explored concepts. Kacy used interactive lectures in which students share their predictions and generated explanations from their observations. She explained:

During the first day of lessons what the students will be doing is that they are going to participate in actually two demonstration labs. One will be a lab set up in the front of the room and one will be set up at the lab tables. And the one they are going to do that they will set up is what I always call my baggie lab. It is the good old iodine and corn starch lab. So before they know anything, they are going to set that lab up. They will make some predictions as to what they think will happen. (pre-observation interview, Day 1)

In the baggie lab, the baggie served as a representation of the semipermeable cell membrane surrounding a starch and water solution. Water and iodine moved freely through the membrane, entering the baggie; but the starch, a much larger molecule remained in the baggie. Iodine, an indicator for starch, changed the white, cloudy starch

solution to a dark blue. Kacy identified the baggie lab as an exploration noting students will predict changes before the concepts of osmosis and diffusion are introduced. She explained: “They [students] will make some predictions as to what they think will happen. Then they will go back to their desks and we will discuss their predictions” (pre-observation interview). Following the discussion, students tested their predictions by observing the baggie and beaker solutions and noting changes.

Kacy incorporated graphics and animations depicting diffusion and osmosis in interactive PowerPoint lectures on Days 1 and 2. She believes animations and graphics are important because tenth grade biology students have a minimal understanding of chemistry and not likely to accurately envision molecular motion as the driving force for both processes. She explained:

I want them [students] to get the idea or the understanding is that diffusion is occurring because of the kinetic energy or the molecular movement and collisions and not because we are adding any outside energy or not because the cell is adding extra energy. . . . So with that website, I was hoping for them to see that molecules are moving and here are more of them and here are less of them and they [the molecules] are moving in this direction due to their relative concentrations. (stimulated recall interview, Day 2)

Kacy utilized whole class discussions as a forum for students to share their ideas and consider alternative explanations for observations made during the investigation. When sharing their ideas, Kacy expected students to cite their observations as supporting evidence for their explanations.

Kacy included two additional representations of osmosis during Day 2. First students observed two decalcified eggs, placed in corn syrup during the previous day and, second, students investigated osmosis in lettuce leaves. She explained:

I have decalcified the eggs and placed them in corn syrup. So the first thing that they will see is the egg all deflated in corn syrup. Then I am going to ask them to

try to explain what has happened to the egg. We are going to use that as our introduction to osmosis. (pre-observation interview)

Prior to observing the eggs, Kacy challenged students to explain how the eggs would change following placement in a highly concentrated solution (corn syrup). Kacy directed students to collaborate with row partners to make predictions which were shared with the class and recorded on the whiteboard. Next, Kacy walked through the classroom with the decalcified eggs, stopping at each desk and encouraging students to observe and touch the eggs to test their prediction. A discussion followed as students used their observations of the eggs and their knowledge of osmosis and diffusion to explain the direction of osmosis. Kacy explained:

They were moving in that direction and were starting to make connections between what was happening with the egg. . . . when we talked about what osmosis is, they were able to make that leap pretty quickly and understand what was happening with the eggs. (stimulated recall interview, Day 2)

Next, Kacy engaged students in an interactive PowerPoint lecture with guided notes; she included diagrams of decalcified eggs placed beakers containing solutions with different percentages of dissolved solids (see Figure 20). She emphasized the relative percentage of dissolved solid in the egg and the surrounding environment in the beaker and challenged students to determine the concentration of water in each solution, and draw arrows to show the direction of osmosis in each decalcified egg diagram.

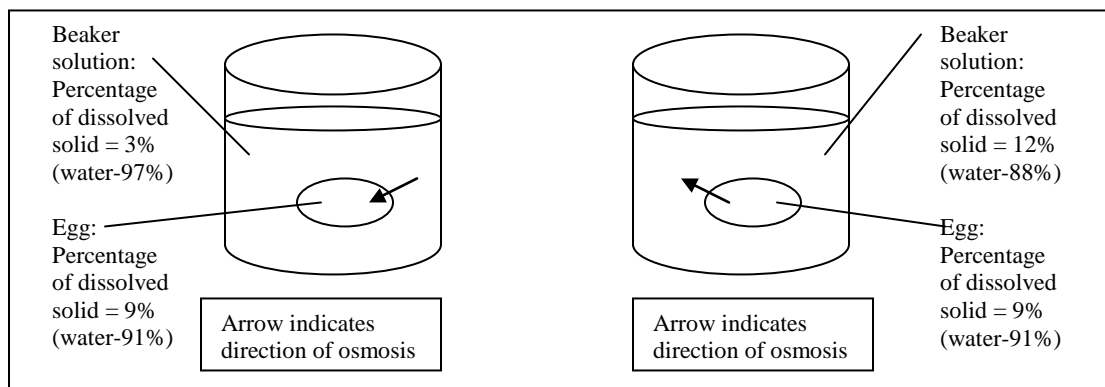


Figure 20: *Representation of osmosis*

The lettuce lab was the second representation of osmosis and diffusion implemented on Day 2. Once again, students made and tested predictions about the direction of osmosis within lettuce leaves placed in three unique environments. Kacy explained:

We are going to practice again with the lettuce lab. So I will have a couple of stations around the room. In each station there will be lettuce in salt water, lettuce in fresh water, and lettuce on a paper towel. . . . From there then they have to try and explain what has happened to the lettuce within the context of osmosis at the cellular and tissue levels. (pre-observation interview)

Kacy challenged students to think about osmosis and diffusion through a series of representations serving as foci for demonstrations, investigations, PowerPoint animations, and guided note sheets. Students were actively engaged in constructing their knowledge of osmosis and diffusion. Kacy explained:

One of our objectives is “Students will be able to predict the direction of molecules”. So that is part of the reason for having students make multiple predictions. So much in this unit deals with predictions because that is one of their objectives. So ‘A’ even before they have the back ground knowledge, practicing and moving through the thought process to make predictions gives them that practice. And ‘B’ it allows me to see where they might be ahead of the game already and where they might not understand things. (stimulated recall interview, Day 2)

Kacy implemented multiple representations for osmosis and diffusion including: corn syrup and food dye placed in water to represent diffusion, a baggie as a representative of a cell and a semipermeable cell membrane, decalcified eggs to represent living cells placed in corn syrup, and three lettuce leaves placed to represent the influence of various environments on plant organs. The representations served as focal points for demonstrations and investigations through which students were challenged to make and test predictions. The instructional strategies Kacy implemented in her teaching actively engaged students in demonstrations and explorations of diffusion and osmosis. The

overarching pattern in Kacy's teaching is her focus on engaging students with demonstrations and investigations in which students were consistently challenged to make and test predictions.

Knowledge of Students' Understanding of Science

Kacy believes vocabulary terms associated with osmosis have the potential to interfere with students' conceptual understanding and the forces which drive both osmosis and diffusion. She addressed her concern by eliminating much of the vocabulary. Kacy did not implement the terms, hypertonic, hypotonic, and isotonic in her lessons. Instead, she focused student attention on the movement of substances from higher to lower concentrations driven by random molecular motion and kinetic energy. She explained, "The students get so caught up in the terms, hypotonic and hypertonic and which one is which, that they lose sight of what the actual concept is" (stimulated recall interview, Day 2). Kacy focused attention on students' understanding the importance of relative concentrations of dissolved solids within solutions to explain the direction of diffusion and osmosis. She explained, "So I want to make sure that they understand the concept of where the concentration of water is greater, where is it less and therefore, be able to predict the direction in which water will move" (stimulated recall interview, Day 2). Thus, she left vocabulary terms and definitions out of her explanations, handouts, and guided note sheets. Kacy explained, "Rather than getting them hung up on the terms, I wanted them to understand the concepts" (stimulated recall interview, Day 2).

Kacy explained that students' learning must be supported with learning opportunities that build upon one another and provide necessary scaffolding. She explained:

So the initial predictions on the very first day, I did not expect them to predict anything correctly. Then with the corn syrup and food dye we were moving in the direction of understanding what the concept is and so it really is a way for me to kind of build on these concepts and for me to assess where their understanding of diffusion and osmosis is and for them to practice what is happening with diffusion and osmosis, to practice that objective. They are able to practice using diffusion and osmosis and predicting what will happen when these processes occur. (stimulated recall interview, Day 2)

Kacy expected students to draw upon previous representations of osmosis and diffusion observed in class to make and test their predictions concerning changes in lettuce leaves placed in three unique environments (distilled water, a saline solution, and on a paper towel in the air). She explained her reasoning for including the lettuce lab during Day 2 by stating:

So this idea of osmosis occurring and this idea of the direction of movement, I wanted them to practice that without me leading the whole group. The lettuce lab is a good little way to do it because lettuce is made up of a lot of water, it is familiar to the students, and they were hopefully able to make some connections between what was happening to the lettuce and what we had been talking about. So I wanted them to make a real life connection. (stimulated recall interview, Day 2)

Continuing to build upon connections between students' lives and lesson content, Kacy noted the importance of maintaining equilibrium between an IV solution and human blood cells. When a student asked how diffusion and osmosis related to their lives, Kacy explained:

I was able to use the idea of the importance of the concentration of the IV solution being the same as the concentration of solutes in the blood. It worked out beautifully because they were able to see how different concentrations of solutes in an IV drip solution can impact the body. (stimulated recall interview, Day 2)

Kacy identified two key areas of student difficulty with the topic of osmosis and diffusion. The first was student difficulty with the vocabulary terms. She noted that students were often confused by the terms and not sure of when and how to use them in

their explanations. To avoid this confusion and focus students on the concepts and the forces that drive osmosis and diffusion, Kacy developed learning opportunities focused on the relative concentrations of dissolved solids and water. The second area of learning difficulty Kacy identified was predicting the direction of water movement. To address this concern, she challenged students with representations of osmosis as the focal point for student laboratory investigations. Thus, students were able to note the direction of water movement in the baggie transport lab, the lettuce leaf lab, and the decalcified egg demonstration.

Knowledge of Assessment.

Kacy noted she relied upon formative assessments including: student predictions, responses to analysis questions, and interaction with students during investigations, to assess comprehension and identify misconceptions. She noted when students made predictions, misconceptions about diffusion and osmosis and the forces which drive them were often revealed. She noted student predictions provided insight into their prior knowledge of diffusion and osmosis. Kacy explained:

I was able to catch student misconceptions about diffusion at the beginning of the hour. I noticed quite a few misconceptions with their predictions about diffusion. . . . Students believed that diffusion could only occur if there was a membrane. . . . Students began the lesson by observing the food dye, corn syrup and water and determined if their predictions were correct and to make sure that we come back and look at it. (stimulated recall interview, Day 2)

Kacy embeds formative assessment strategies into her teaching. Students developed written explanations for analysis questions following the lettuce investigation. Kacy reviewed students' work and responded in writing offering suggestions for improvement to each student. She believes assessment provides important feedback about student learning and the effectiveness of instructional strategies and representations.

Kacy does not formally grade all student work; however, she reads their responses to analysis questions to gain insight into their thinking. Kacy explained:

We practice giving that good explanation with the egg and with the lettuce and what not. All of these are going to be practice that I do not give them a grade on but I give them that scaffolding so that they are able to eventually understand and then demonstrate that they understand the concept. (pre-observation interview)

Kacy described herself as a careful observer and noted she moves around the classroom when students are working individually or in teams, to monitor their ideas and explanations, to determine accuracy, and to identify misconceptions. She noted that initially students did not understand why diffusion takes place; this knowledge informed her next steps in the lesson. She explained:

I used assessment throughout the lesson to show me where I needed to go next and where the students' learning is at that point and what else we need to do to practice those concepts. For example, just doing the corn syrup demonstration that showed me that we really need to practice I asked them to get with their partner and check the definition of diffusion. That really spoke to me and made me realize that they really did not remember anything that we did during the last class period. So we needed to just go back and remind ourselves of what diffusion is and what concentration gradients are. (stimulated recall interview, Day 2)

She assessed students' progress during the lesson by listening to their discussions while constructing explanations for the analysis questions. She described her assessment during the baggie transport lab:

With the baggie lab I am going to move around and I will be listening to what their answers are to determine if they are grappling with concepts. That will be a formative assessment for me to see where they are in their understanding of the concepts. (pre-observation interview)

Kacy read and responded to student explanations for analysis questions and noted students were beginning to understand the connection between the relative concentrations of dissolved solids and the direction of osmosis in that water will diffuse from higher to lower concentrations. She noted:

I just went over them [lettuce lab-analysis questions] a little while ago and most of them understood that there was a higher concentration of water outside of the lettuce leaf than there was inside and therefore, the water would move into the lettuce leaf cells. That leaves us with osmosis as a type of diffusion and we are moving in that direction. (stimulated recall interview, Day 2)

Kacy believes that assessment for learning does not necessarily result in a grade but rather provides formative feedback for students to use to review and revise their work. When Kacy responded to students' lettuce lab analysis questions she provided comments and suggestions for improvement. She explained:

A lot of them drew the arrows but did not put in the high and lower concentrations of water so I put in the concentrations of water. So they got constructive feedback from me to help them continue to improve their answers. So that showed me where their understanding is and I would say that 95 percent of the students correctly predicted the direction of movement of the water. (stimulated recall interview, Day 2)

Kacy utilizes feedback from formative assessments to inform her teaching. She explained that by reviewing student work she can identify specific difficulties students are experiencing. She noted student progress as she moves through the room while students are working provides valuable insight into student comprehension. Kacy noted that misconceptions can be identified by carefully assessing students' predictions, explanations, and conversations. Student feedback from formative assessments informs Kacy's next steps in her lessons. She has the potential to make adjustments to her lessons to better meet the learning needs of her students.

Knowledge of Curriculum

Kacy explained that biology curriculum development is carried out by the Professional Learning Team (PLT) team at her school and noted the PTL is guided by state Course Level Exams (CLE) as well as the district biology curriculum. The sequence of content along with curricular resources including: guided notes, laboratory

investigations, demonstrations, and summative evaluations, were largely developed through collaboration within the PLT. Kacy noted the sequence of instruction is important and explained she engages students with explorations of phenomena prior to generating explanations. Explanations are generated interactive lectures when students are sharing the accuracy of their predictions, their observations, and their explanations for changes observed during the investigation.

Kacy believed students are confused by osmosis and diffusion and require multiple opportunities to refine their thinking to create a deeper and more accurate understanding of the concepts. She explained:

I think one thing that I have had a revelation about over the last couple of years is that students need many different avenues to practice these concepts and they have to be able to. You just do not explain cellular transport, you have to scaffold their ability to explain cellular transport so by providing lots of different scenarios even though we are dealing with the same concept over and over and over again. (pre-observation interview)

Kacy explained her students rely heavily upon the information provided in interactive lectures with guided notes sheets and animations of osmosis and diffusion. She believes animations depicting molecular motion during osmosis and diffusion enhance student comprehension of abstract concepts such as molecular motion and concentration gradients. Kacy explained, “I wanted them to start to see what is happening during osmosis. It is so hard for them [the students] to visualize and conceptualize what is happening because molecules are so abstract to them” (stimulated recall interview, Day 2). She explained her implementation of animations:

At this point, they have had no chemistry other than we had a mini-unit on what molecules and atoms are. So that is all they have had in terms of their chemistry. So when we start talking about the movement of molecules, it is such an abstract concept for them that anything that I can do to help them visualize it a little bit

will help the concepts to become less abstract for them. (stimulated recall interview, Day 2)

Kacy believes analogies and metaphors strongly support student comprehension by creating a concrete image of an abstract concept. She noted, “We use analogies and metaphors all of the time and we talk a lot about moving from a higher concentration to a lower concentration and we talk about being in a big crowd of people and bouncing off of each other” (pre-observation interview).

The biology curriculum results from a collaboration of the PLT which Kacy indicated is guided by the state CLEs along with the district curriculum. She explained that the PLT is responsible for the major curricular decisions, but she has autonomy in her classroom and implements learning opportunities taken from a wide range of curricular resources. The textbook is not a focus for Kacy’s teaching and noted curricular resources include the PTL, key websites, laboratory notebooks, textbooks, and her colleagues. She noted that osmosis and diffusion are important and link key concepts in chemistry and biology creating a bridge between molecular motion, cellular membranes, and homeostasis within living systems.

Kacy’s PCK for Teaching Diffusion and Osmosis

Kacy initially engaged students with explorations and followed a sequence of instruction similar to that of the 5E instructional model (Bybee, 1997). She consistently challenged students to make and test predictions and encouraged students to construct their understanding of osmosis and diffusion from their observations and experiences with the concepts. Therefore, I posit that Kacy holds a constructivist orientation to science teaching. Kacy’s knowledge for teaching osmosis and diffusion is shown within the context of the Magnusson et al. (1999) model of PCK is shown below in Figure 21.

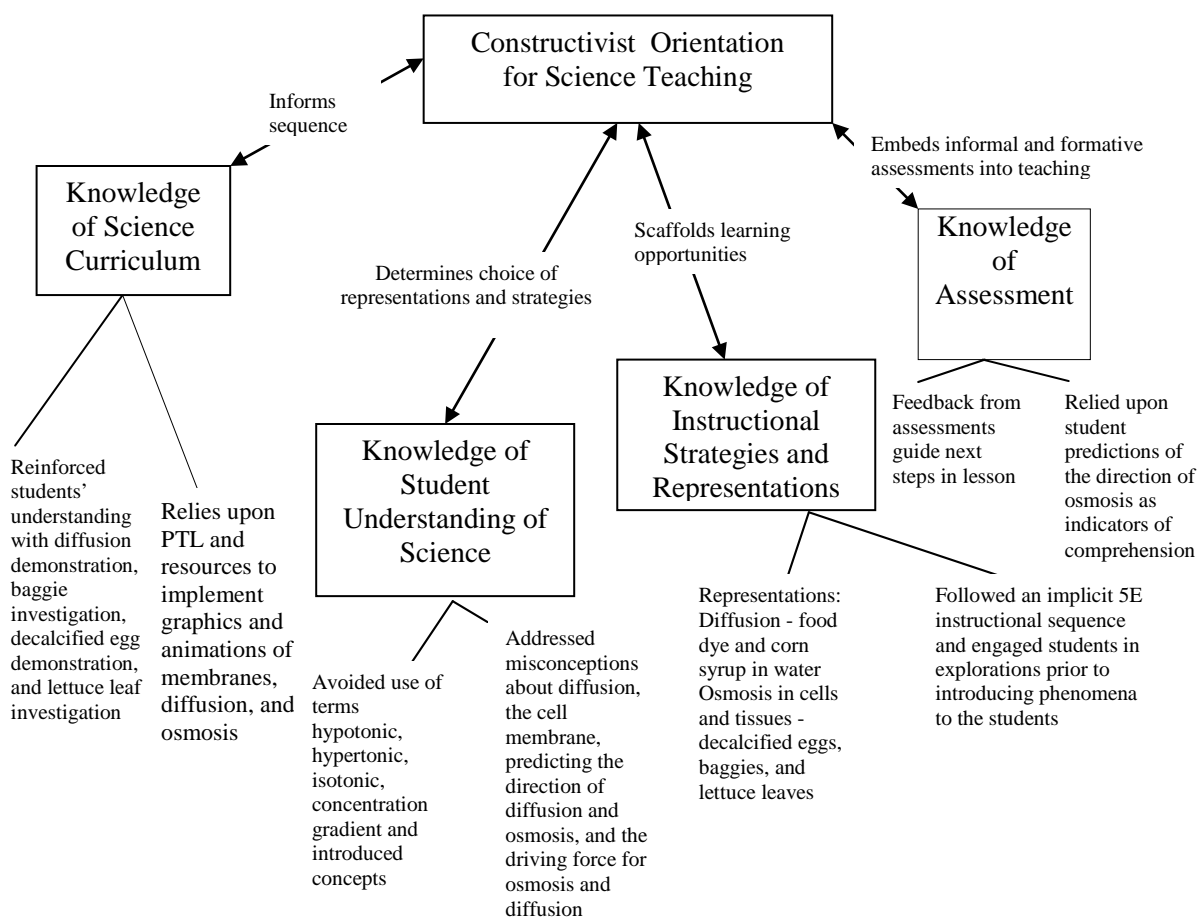


Figure 21: Kacy's topic-specific PCK²¹

Kacy demonstrated strong knowledge representations which served as focal points for investigations and demonstrations and made relevant connections to students' prior knowledge and experiences. She believes students can learn from each other and encouraged cooperative learning through students' collaboration with peers to make and test predictions, gather evidence, and respond to analysis questions. Kacy relied upon students' predictions to gain insight into students' thinking, identify misconceptions, and

²¹Note: Modified from Nature, sources, and development of pedagogical content knowledge for science teaching (p. 99), by S. Magnusson, J. Krajcik, & H. Borko, 1999. In Gess-Newsome & N. G. Lederman (Eds.), *Examining Pedagogical Content Knowledge*. Boston, MA: Kluwer.

inform the implementation and sequence of representations and instructional strategies within the lesson. Kacy's knowledge of students as learners informed her perception of vocabulary (hypertonic, hypotonic, isotonic, and concentration gradient) as a potential constraint to student learning resulting in her decision to avoid vocabulary and focus on students' conceptual understanding. Kacy's integration of the components PCK components for teaching diffusion and osmosis is shown in Figure 22.

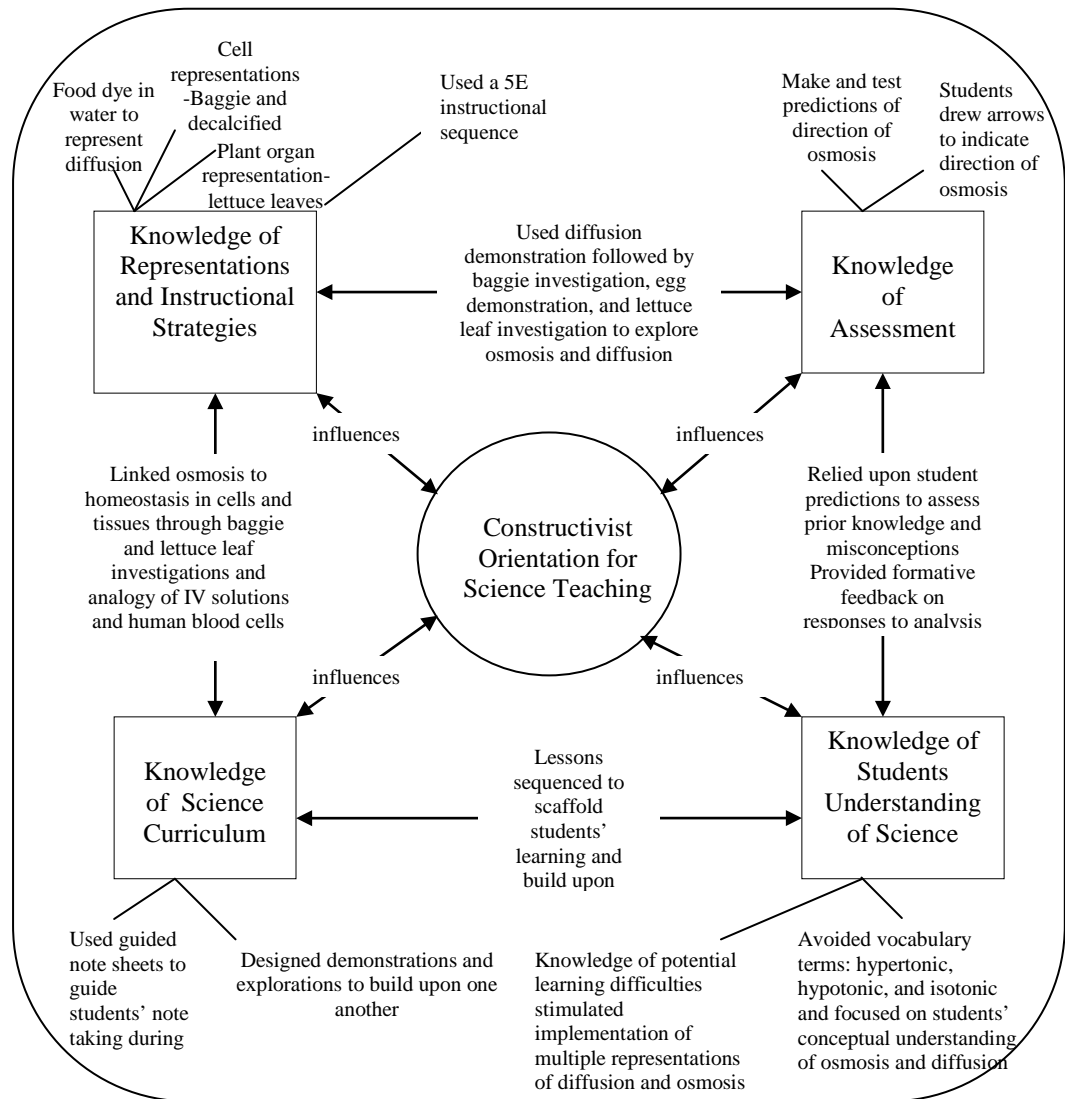


Figure 22: *Integration of Kacy's topic-specific PCK*

There are four important features to note within this representation. First, Kacy's orientation to science teaching is central within the model indicating the importance of her constructivist orientation acting as a lens through which the components of PCK are integrated in the development and enactment of learning opportunities. Second, four boxes each representing the components of Kacy's PCK are connected with reciprocating arrows to Kacy's orientation to science teaching, indicating her orientation to science teaching influences each of the components of her PCK and is, in turn, influenced by the components of her PCK. Third, connecting arrow between the components of Kacy's PCK indicate the highly integrated nature of Kacy's knowledge. Fourth, connecting statements between components provide insight into Kacy's rationale for the integration of knowledge for teaching diffusion and osmosis.

Kacy drew heavily upon her knowledge of students as learners when designing and teaching lessons; she believed students were capable of learning through active engagement with content and designed lessons to include multiple opportunities for students to investigate osmosis and diffusion within representations of cells and tissues. Her knowledge of representations, strategies, students, and assessments implemented in the lessons were reflective of her goals for student learning and knowledge of potential learning difficulties. She embedded formative assessments into her lessons, relying upon the nature students' predictions and explanations to inform next steps in her lessons. She used her curricular knowledge to sequence lesson content with explorations of concepts preceding explanations. Kacy integrated all four PCK components when teaching diffusion and osmosis.

Content representation

In Table 24, a Content Representation (CoRe) illustrates Kacy’s knowledge of teaching. The components of PCK are represented within the context of the CoRe and specific examples of instructional strategies and representations, assessments, potential student difficulties, and curricular considerations are include. When reading the CoRe, it is important to read individual columns (e.g. Big Idea A) from the top to the bottom vertically. The columns extend beyond a single page.

Table 24. *Content representation for Kacy*²⁴

Considerations	Content Representation (CoRe)		
	Big Idea A	Big Idea B	Big Idea C
	Passive transport involves the movement of materials from areas of higher to lower concentration without the expenditure of energy.	Osmosis and diffusion occur within living systems and allow cells to maintain a unique environment within the cell.	Osmosis is defined as the diffusion of water through a semi-permeable membrane. The direction of osmosis is determined by the relative concentrations of dissolved solid; water will diffuse from higher concentration to an area of lower concentration.
Identify the learning goals for students within this lesson?	Define passive transport and explain the importance of passive transport in living systems.	Explain how diffusion and osmosis occur within cells and why it is important for cells to undergo osmosis and diffusion.	Given an example, be able to accurately predict the direction of diffusion.
Why is it important for students to know this content? <i>[Knowledge of curriculum]</i>	<ul style="list-style-type: none"> • Passive transport is one way that materials enter and leave the cells which does not require energy and follows the concentration gradient. • Kinetic energy and molecular motion are the driving forces for diffusion and osmosis. 	<ul style="list-style-type: none"> • Diffusion is one way in which materials necessary for life enter cells and some waste products leave the cells. • Diffusion is important in the passive transport of small, uncharged inorganic molecules such as H₂O, O₂, and CO₂ into and out of the cell to maintain homeostasis. 	<ul style="list-style-type: none"> • Osmosis works through diffusion when water molecules diffuse from areas of higher concentrations to areas of lower concentration through a semi-permeable membrane. • Water is necessary for life and osmosis is the means by which water enters and leaves the cell.

<p>Identify potential student difficulties and limitations associated with teaching this idea. <i>[Knowledge of students as learners]</i></p>	<ul style="list-style-type: none"> • Kinetic energy and molecular motion are abstract concepts and may be difficult for students to perceive as the driving force of passive transport [diffusion and osmosis]. • An increase in kinetic energy results from an elevation in heat energy. An increase in kinetic energy increases the rate of diffusion. 	<ul style="list-style-type: none"> • Vocabulary terms can be confusing for students and inhibit their ability to understand the concepts of osmosis and diffusion. 	<ul style="list-style-type: none"> • Accurately predicting the direction of osmosis and diffusion may be difficult for students. • Understanding the connection between relative concentrations of dissolved solid within two solutions and the direction of osmosis may be difficult for students. • Explaining diffusion in living and non-living systems can be problematic for students because many believe diffusion only occurs in cells with membranes.
<p>Teaching strategies and representations implemented and particular reasons for using these strategies to engage students with this idea. <i>[Knowledge of instructional strategies and representations]</i></p>	<ul style="list-style-type: none"> • Engaging students with demonstrations and investigations of diffusion and osmosis will provide the experience necessary to support their conceptual understanding of the phenomena. • Students will note the diffusion of iodine and distilled water into the baggie occurs as a result of the difference in the concentration of dissolved solid within each solution. 	<ul style="list-style-type: none"> • Introduce diffusion to students through a diffusion demonstration in which droplets of a concentrated solution of food dye and corn syrup are placed in distilled water. • Use students' predictions to focus student thinking, reveal prior knowledge, and engage students in critical thinking. • Students predict the diffusion of iodine into a baggie containing a starch solution. Iodine will turn the starch solution from white to a dark blue or black color if it diffuses through the baggie. 	<ul style="list-style-type: none"> • Make and test predictions about changes: <ul style="list-style-type: none"> ▪ In a baggie containing a starch solution placed in a beaker of distilled water and iodine. ▪ In a decalcified egg after placement in corn syrup. ▪ In lettuce leaves placed in three different environments: distilled water, saline solution, and on a paper towel in the air.
<p>Identify ways of ascertaining that students understand the concepts taught. <i>[Knowledge of Assessment]</i></p>	<p>Student responses to the analysis questions provide insight into their thinking about applications for osmosis and diffusion in living cells.</p>	<p>Listening to students' comments, questions, and conversations during collaboration is an effective way to gauge student comprehension.</p>	<p>Students consistently make and test predictions for all demonstrations and investigations. The nature and accuracy of student predictions provides insight into student preconceptions and misconceptions.</p>

The CoRe provides an overview of Kacy's topic-specific PCK and describes her teaching practice.

²⁴Note: Modified from *Understanding and developing science teachers' pedagogical content knowledge*, by J. Loughran, A. Berry, and P. Mulhall, 2006, p. 28. Rotterdam: Sense Publishers.

Lana's Case Profile

Lana's Vignette: Investigating Osmosis and Diffusion with Baggies

“Okay everyone, I want you to listen carefully; today we are going to investigate osmosis and diffusion. Remember, yesterday we talked about how substances diffuse from higher to lower concentrations,” Lana explained. Students are placing their book bags on the floor and science notebooks on their desks. The room is small with lab tables arranged in a horseshoe pattern; in the center of the horseshoe there are three rows of lab tables. A combination of books and equipment is found on shelves lining the walls; making the room seem even smaller. Behind Lana, a PowerPoint slide with a single warm-up question is projected on a screen.

“Are we going to do a lab today?” a student calls out from the back of the room.

“Yes!” calls out another student; “I really like to do labs, we get to work together and it’s fun.” “Can we please do a lab today?” another student calls out.

“Well you guys are ready to go, aren’t you” Lana comments. “While I take attendance today, I want you to respond to the warm-up question on the PowerPoint slide.” Lana reads the question on the screen: “The cell theory states that cells are the basic unit of structure and function in living things and all living things are made up of cells. What substances must enter cells to support life?”

“Write what you think those things are that cells must have to support life in your notebook,” Lana explains. Then I would like you to explain why cells need those things and how those things would get into the cell.” The students begin to write their responses to the question in their notebooks while Lana carefully takes attendance.

Three minutes later the room is quiet but some of the students are beginning to look around. Lana asks: “Well, how did it go, what are the things you chose to write in your notebooks. Let’s make a list on the board.”

“Jeremy, tell us one thing on your list?” Lana asks Jeremy who is trying to capture the attention of someone on the other side of the room. “Jeremy, I am talking to you!” Lana raises her voice slightly.

“Oh, sorry,” Jeremy responds and some of the students laugh as he blushes. “I think that cells would need some kind of food” Jeremy quickly states.

“Mrs. M, all things need food, right?” Another student asks.

“Right, so why do you think the cells will need food, Jeremy? Lana asks.

“Because, cells have to be able to make energy and make stuff like organelles; we talked about last week” Jeremy responds.

“Lisa, do you have anything else to add to Jeremy’s ideas?” Lana asks.

“Well, I think that all living things need water; like how long would anything live it there was no water?” Lisa responds.

“I’ve got one” a student in the back of the room calls out as he raises his hand.

“Most things need oxygen to survive, right? The student calls out.

“Good. You guys are really on top today!” Lana responds.

“Mrs. M, I think that we have got the three things that really count.” Darius calls out from the back of the room.

“How so, Darius?” Lana asks.

“Hey, cells are alive so they need some kind of food to make energy, and nothing can live without water, and most everything needs oxygen, right?” Darius responds.

“Vitamins, hey, cells got to have vitamins,” another student comments.

“Good one, you guys have it together” Lana proclaims as she adds to the list on the board.

“Good job guys; so how do you think these things get into the cell?” Lana asks looking around the room. “What do these substances have to go through to get inside the cell?”

“They have to go through the cell membrane, yeah, I remember this from yesterday” a student responds.

“We talked about cell membranes in class yesterday. Remember, Ms. M. said that cell membranes were like race tracks because the lipids can move,” states a student.

“Well, we are going to investigate how substances might get into cells by creating a model cell, yesterday we talked about water diffusing through a membrane” Lana explains. “Today, we are going to use a baggie to represent a cell and help us think about how a membrane might work.”

“A baggie?” asks Jeremy.

“Yes, Jeremy, a baggie,” Lana explained: “We can seal the baggie so that the only way for something to get inside the baggie is through the baggie itself.”

“Look at the protocol on the screen” Lana directs as she transitions to the next PowerPoint slide. “This slide is actually the protocol for the baggie investigation lab.”

“Okay, first, you and your lab partner will pour 100 milliliters of a corn starch and water solution into the baggie.” Lana holds up a beaker of the cloudy starch solution.

“Second, you will then seal the baggie, mass it, and place the baggie in a beaker of

distilled water. Finally, you will add 10 drops of iodine to the water in the beaker,” Lana explains as she holds up an amber dropper bottle containing iodine.

“So why do we need iodine?” Darius asks.

“Ms. M., how can we tell if the iodine and water enter the tube by looking for a color change in the starch solution?” Jeremy asks.

“Watch this,” Lana adds several drops of iodine to a test tube containing the starch solution.

“Far out!” several students call out as the starch solution in the test tube quickly turns from cloudy white to dark blue color with the addition of iodine.

“Now, how would you answer Jeremy’s about iodine in this investigation?” Lana asks.

“Like, iodine will cause the starch in the baggie solution to turn dark,” students respond.

“Now, before you begin, talk with your lab partner and make a prediction about what you think will happen to the solution in the baggie and beaker,” Lana explains. For the next couple of minutes, students are discussing the lab and writing their predictions in their notebooks.

“Okay, guys. The list of what you will need is on the slide along with the protocol for our investigation today. Get into your lab groups, follow the directions and we will see what happens” Lana calls out as she stands by lab desk in the front of the classroom, ready to help her students pick up materials.

The students move around the room, getting into their lab groups, gathering materials, and setting up the baggie lab.

Background and Context

A veteran science teacher, Lana taught general biology, earth science, and college biology at Miller High School for over 19 years. Miller High School is located within a small, rural, mid-western community and includes grades from 9 through 12 with an average class size of 24 students, above the state average of 18 (DESE, 2008). The only high school within the district, Miller High School is on a traditional schedule with 48 minute class periods.

Lana's classroom is small with students seated at lab tables rather than individual student desks. Lab tables are arranged in a U-shape around the perimeter of the room; the center of the room consists of three rows of two lab tables each. Each table seats two students. The small size of Lana's classroom places students within close proximity to one another and offers only limited lab space for laboratory investigations. Two partial lab stations are located in the front and back of the room; both stations consist only of a sink with running water, there are no gas jets in the room. Old textbooks, glassware, and equipment are stored on open shelves lining two walls of the room. Lana indicated that she has only limited access to the chemistry lab located down the hall and explained the lack of equipment, materials, and space continues to be a serious constraint to incorporating laboratory investigations into her curriculum.

Orientation to science teaching

Lana's orientation to science teaching is best described by addressing aspects of her instructional practice in terms of her goals and purposes for science teaching, perception of the teacher role, perception of the student role, ideal images of teaching, and her view of science as a discipline.

Goals and purposes of instruction. Lana's overarching purpose for teaching biology is to enhance students perception of biology and support students' understanding "that science is not a collection of little bits of information, I mean everything is connected," (pre-observation interview). The goals Lana emphasized for Days 1 and 2 are (a) to enhance students' understanding of the nature and structure of the cell membrane and (b) to support students' conceptual understanding of osmosis and diffusion. She also planned to spiral back to the cell theory to enhance students' understanding of the cell as the smallest structural and functional unit in all living things. Lana explained:

I have two purposes. One, I definitely want to engage them in this idea of how important the cell membrane is. Then from there, I want to get them into the complexity of it and how it functions with the phospholipids, how things move across that membrane. So we will talk about how things move in and out of the cell. Because it [the cell] is a living entity I am planning to make a reference back to the cell theory that we have addressed last week, so that they can relate to the cell as a living thing, the smallest living unit. (pre-observation interview)

In essence, she wanted her students to understand the relevance of the cell membrane in terms of maintaining homeostasis within the living cell. Lana believed her students were not prepared to conduct an exploration of phenomena. She explained:

The students at this level really do not have enough background knowledge to do that. Sometimes I think well maybe I am being too possessive but only, we are just beginning our second quarter and my students have not done very many labs even as freshmen. (stimulated recall, Day 1)

Hence, Lana's goal is to support students with the laboratory investigation planned for Day 2 with a lecture explaining the process of diffusion and osmosis.

The lesson on Day 1 was designed to serve as an introduction to the structure of the cell membrane. Lana noted:

My number one goal was to introduce cell membranes and their complexity and for the kids to become aware of the parts of a cell membrane that was the big one for today; that would be my number one. (stimulated recall interview, Day 1)

Lana identified the purpose for Day 2 as the development of students' conceptual understanding of the function of the cell membrane in terms of maintaining homeostasis through osmosis and diffusion. She explained:

For tomorrow I want them to get into the function, why the membrane is important. For today [Day 1] it is just about the membranes. They are aware that cell membranes exist. And I was glad that they recognized because I mentioned it several times that there are cell walls and the cell membranes are inside the cell walls. (stimulated recall interview, Day 1)

On Day 2, Lana planned to for students to apply the knowledge of diffusion and osmosis gained through the lecture on Day 1 to a baggie investigation. She planned for students to observe and measure the diffusion of small molecules (water and iodine) through a sealed baggie. Lab protocol required students to determine the mass of the baggie and starch solution before placing the baggie into a beaker of distilled water and iodine. Lana challenged the students to predict changes they would see in the baggie and beaker solutions on the following day when students would observe both solutions and mass the baggie again to test their predictions. Even though Lana described the investigation as student generated, the protocol was provided with students left to design a hypothesis and predict potential outcomes. She described her students as not quite ready to generate investigations as explorations. Lana addressed the structure of the membrane during a PowerPoint lecture on Day 1 during which she also introduced osmosis and diffusion as means by which materials enter the cell. Thus, she implemented the baggie investigation as a validation rather than an exploration of the osmosis and diffusion. She noted students would have difficulty conducting the investigation without guidance; thus, her instructional approach is traditional. She explained: "So even doing a lab where they

pick up the materials and the equipment and things seems like a big production”
(stimulated recall interview, Day 1).

Lana explained that she planned to focus students’ attention on the movement of iodine and water into the baggie, emphasizing osmosis and diffusion. She explained: “I am going to get into more of the osmosis because I am hoping that there will be water going into the baggies too.” (stimulated recall interview, Day 2) Thus, Lana planned to use the baggie investigation as an opportunity for students to observe and quantify evidence of osmosis and diffusion. She intended to use the baggie lab as springboard for students to design their own experiment during the following week when decalcified eggs serving as a cell models would be placed in environments of distilled water and corn syrup. She explained:

It is another way for them to elaborate or expand upon what they have learned so that they get a better grasp. It is a great way for them to practice hypertonic and hypotonic solutions. . . . Then when they put the egg into Karo syrup, the water leaves the egg just as rapidly. It is just so visible that they cannot miss it. They will remember. (stimulated recall interview, Day 2)

Lana noted her overarching purpose in teaching biology is to help students understand and appreciate life and life processes. She explained:

I want them [students] to appreciate life and this whole complex entity of biology and how things fit together. . . . I want them [students] to be able to understand basic concepts in biology because I think if you are a voter or a consumer, those are so important. (pre-observation interview)

Therefore, she believes the emphasis in high school biology should be to prepare students to be thoughtful consumers and citizens, relying upon a general understanding of biological concepts to make wise decisions as responsible consumers and citizens. Lana’s overall purpose is to instill within students an appreciation of life and basic principles of biology.

Perception of teacher role. Lana described the role of the teacher as that of a facilitator. She believes her role as a teacher is to engage students in science through activities and investigations that make biology content understandable. Lana explained:

I feel very strongly that I am, and the word that comes to mind, is a facilitator. . . . I truthfully am not as comfortable being the lecturer or the guru on the stage saying, this is the information and please record it and put it down. I am much happier when these kids are doing things. (stimulated recall, Day 2)

As a facilitator, Lana explained she tries to engage students in learning science through laboratory investigations as often as possible. Lana explained, “I truthfully try two or three times a week or more and I use labs as an engagement piece when we start a unit” (stimulated recall interview, Day 2). Lana was part of a university program, Partnership for Research and Education with Plants (PREP). The goal of the program is to support teachers with the implementation of student-driven research into high school biology. Lana expressed her desire to incorporate student-driven research into her curriculum but noted she had difficulty implementing PREP into her teaching. As a result, Lana has become inactive in the program, no longer attending workshops and sharing her teaching experiences with her peers. Lana’s places greater emphasis upon student retention of content knowledge and, even though she was enthusiastic about PREP, she was not able to implement learning through exploration into her teaching.

Lana believes students often learn best when they are active participants; however, Lana noted that students may struggle with learning and benefit from a variety of strategies including lecture, discussion, demonstrations, and investigations. She explained:

I just think that you need a variety of strategies with your kids and with their learning to enhance student learning. It changes from unit to unit; sometimes they

just nail it and understand the concepts right away and other times they need more experience with the concept. (stimulated recall interview, Day 2)

Lana believes she is laying the groundwork for students' knowledge of biology; she noted that one concept builds upon another and it is important to make connections to concepts taught earlier. She explained, "So you set the ground work and one thing builds upon another and you keep spiraling back and pulling it forward so hopefully by the time they exit in May, their depth of knowledge is broadened. It is expanded" (pre-observation interview). She noted the importance of analysis questions following a laboratory investigation. Lana explained:

I decided that I need to do better, more in-depth questions so that they are not just writing, "It was a liquid." Instead they have to provide a more complete answer to explain their observations. That is a challenge and it is one that I welcome because that is why we are here as teachers. It is not just to provide an opportunity to play at biology. I want them to make connections there is a reason that things worked that way it was not just a magical, one time thing. (pre-observation interview)

Lana believes many of her students will not go on to college, emphasizing the importance of high school biology as a basis for decision making in life. She noted:

I have always felt and I am not trying to create doctors or research people as much as I want them to ask questions and to appreciate life. Then if it goes on to those higher levels then that is wonderful but I want them to be the type of citizens that appreciate life and how all of these things fit together. I want them to think 'Wow, this was neat.' Also I want them to be able to understand basic concepts in biology because I think if you are a voter or a consumer, those are so important. (pre-observation interview)

Lana noted with classroom experience, her understanding of students' learning needs increased resulting in the development of analogies to make connections between students' experience and biological concepts more evident. She explained her repertoire of representations for biological concepts has grown with her experience in the

classroom. Lana reported using analogies to make concepts more understandable for students. She explained:

I use and I like analogies and I started years ago to develop analogies for some units. Like I have some analogies for ecology and I love developing analogies, like this is to this as this is to this. We have had some real good discussions with this group because I told them that if they can justify how they could fit their ideas in their ideas [analogy] would be accepted. But it has to be justified. I went Oh, because I have some analogies that I have worked on for cell structures that will probably follow this membrane unit. I like analogies and I also have a project I do with cells and this is kind of a spin off. (pre-observation interview)

Lana noted the importance of spiraling back to make connections between earlier concepts. She noted her goal in doing this is to provide students with an opportunity to see concepts in biology as connected. She noted:

Oh, all year I spiral back. Whatever I teach it comes back around with references to what I taught because I feel that biology all fits together. I think that it is exciting and I get very excited about what I teach because there is so much to learn and it is an ongoing learning process and I want the kids to realize that it is manageable and it fits together. It is a big puzzle and we continue to find the pieces that fit together. (pre-observation interview)

Lana hoped to facilitate students' conceptual learning and noted "It is not about regurgitating the information, it is about applying it" (stimulated recall interview, Day 2). Lana noted that she wants students to perceive science as a way to understand the natural world and as a means through which answers can be found. Thus, she believes that by offering students a variety of experiences with content, she is making science more understandable and relevant for students.

Perception of student role. Lana explained that to be successful, students must take responsibility for their own learning and when students do not accept this responsibility, learning is a struggle. She explained:

I am hoping that they [students] are engaged and that they will be considerate and, in an ideal world, focused on what we are doing. I realize that we are in a world of

multi-tasking and we all do it. I realize that there are other things on their minds. But when I have an assignment for them to complete I think that their role [student role] is to complete that. (stimulated recall interview Day 2)

She places significant importance on homework and identified homework as an opportunity for students practice and one of her students' most important responsibilities. Lana believes after school employment, athletics and social activities must take second place to their learning. She explained:

They have major responsibility. I feel really strongly that being a student is their number 1 job at this time. . . . Working a job should be second or third if at all. Their priority and their job should be to be a student. (stimulated recall interview, Day2)

Lana strongly believes to be successful learners students must accept responsibility for learning. She expressed frustration when students are unprepared for class and have not completed assignments on time. Lana explained her major role as a teacher is to engage students in learning and stimulate their interest in science to make learning more interesting and engaging and the role of the student as taking full advantage of available learning opportunities.

Ideal images of teaching. Lana described her idea images of teaching as engaging students with activity-based investigations and guided inquiries. When Lana talked about her practice as a teacher, she described herself as facilitator and explained that she perceives her role in the classroom as “one who has access to information and provides various ways for these students to understand and unlock meanings” (stimulated recall interview, Day2). Lana explained she works to construct connections between content to make biology relevant for students. She explained:

Oh, all year I spiral back. Whatever I teach it comes back around with references to what I taught because I feel that biology all fits together. I think that it is exciting and I get very excited about what I teach because there is so much to

learn and it is an ongoing learning process and I want the kids to realize that it is manageable and it fits together. It is a big puzzle and we continue to find the pieces that fit together. (pre-observation interview)

Lana engaged students with a warm-up question on both Days 1 and 2 and noted the questions were designed to stimulate students' thinking about the lesson topic. She believes a warm-up is a means to make sure everyone is on the same page and focused on lesson content. She explained:

Well traditionally that is how I do the warm-ups because I want the kids to be engaged. . . . I wanted to make sure that we all had the same answers for the question. So I wrote it on the board and I also had it on the overhead. I wanted to make sure that we were all on the same page. I wanted to make sure that we were starting out together with the same ideas. (stimulated recall interview, Day 2)

Following the warm-up question on Day 1, Lana implemented traditional instruction utilizing a PowerPoint lecture to introduce vocabulary terms and definitions. A discussion of the structure and function of the cell membrane followed the lecture. Lana noted this was not her preferred mode of teaching; her preference is to first engage students an investigation designed to focus students on an exploration of the concept. She explained:

I am introducing concepts and doing the background and we will go from there. Normally I would do more of an engagement piece and we would go from there. Many times I do the activity and when they are into it that is when they really feel the need to know the terms and what they mean. Rather than attempting to learn them in advance, they don't but they are exposed to them but may not actually learn them in advance. (stimulated recall interview, Day 2)

Lana described the manner in which she preferred to teach as actively engaging her students in doing science by conducting investigations and challenging students to think critically to answer questions. She believes that students learn most effectively when they are engaged in learning and challenged to apply their knowledge to answer questions or solve problems. She noted that when students engaged in doing science, they

are more likely to ask questions and search for answers. She explained that she finds collaboration to be an effective strategy to achieve her ideal:

I prefer to have them do hands on and then to go on and explain the concepts. They are doing things and then they are back and they are asking questions. I love something where there are good strong questions. It takes a while to get those sometimes. When they are asking you “I did not understand” and maybe they are interacting within a small group. That is my preference. (stimulated recall interview, Day 2)

She explained that even though teacher-centered instructional strategies (e.g., teacher-directed lecture) may be the easiest to implement, passive learning is not effective learning for most students. Lana explained:

The easiest way to teach and my least favorite and the one I hate to see is the notes and the kids copying that. I have tried to do better with printing off the PowerPoints with my kids like they do in college. But still it is not very good learning; it is basically information and when they are writing those notes all they are doing is transcribing. (stimulated recall interview, Day 2)

However, Lana used teacher-directed lecture to initially engage students with diffusion and osmosis. During the lecture on Day 1, she explained the nature of a semipermeable membrane, as well as the processes of diffusion and osmosis to her students. Hence, even though Lana described her ideal image of teaching as developing community-based learning challenges for her students and envisioned her students investigating relevant problems within the community. She explained:

I have this dream that I will come up with this idea, maybe a community service idea or something and we can wrap what we are studying around it. An environmental problem is very personal and we can do the chemistry and whatever. The kids are so engaged. Would that not be ideal? (stimulated recall interview, Day 2)

Her actions indicated a strong reliance upon lecture and the transmission of knowledge within her teaching.

Lana's ideal image of teaching involves engaging students with collaborative activities focused upon realistic and relevant issues, searching for new knowledge, and challenging students to apply their knowledge of biology to solve real-world problems. She explained that she believes that students learn most effectively when they are actually engaged in learning science and applying their knowledge to answer questions or solve problems. She noted that even though she relies upon knowledge-transmission strategies (e.g., traditional lecture), she prefers to teach by engaging students with activities.

View of science as a discipline. Lana explained that she perceived science to be a way of knowing rather than clusters of facts about plants, animals, and the environment. Lana emphasized that science is a problem solving method that relies upon evidence rather than facts to be memorized about the natural world. She explained:

I want the students to have an appreciation that science wants to understand things; that it is a whole process of acquiring information and knowledge and making those connections and trying to figure out how things work together. (stimulated recall interview Day 2)

Lana emphasized the importance of engaging students with science as a way to understand how living and non-living things interact in the natural world. She explained that her focus was not on terminology but on conceptual understanding of scientific concepts and processes within the natural world. Lana explained that she wants her students to understand the importance of evidence and how new technologies can influence perceptions of scientific knowledge. Lana explained:

I think that when it is all over it is not so much the mastery of terminology. I want them to get a feel for what science is and how science works. We ask questions and we look at things, we want statistics and data and it can change based upon addition data and new ways to look at things. But I really think that when they

leave I want them to have a feeling about what science is and how it works.
(stimulated recall interview, Day 2)

Lana emphasized that she perceives science not as terminology and clusters of facts related to plants, animals, and the environment but rather as a perception of how living and non-living things interact in the natural world. She perceives science as a way to understand the natural world by posing questions and seeking answers. She noted understanding interactions in the natural world is more important than understanding terminology and relied upon lecture and discussion to explain the interconnectedness of the natural world for her students.

Summary of Lana's orientation to science teaching. Lana identified several experiences which informed her goals and purposes for teaching biology. She noted her experience teaching tenth grade biology in a small, rural community had an important influence upon her beliefs about teaching, learning, and learners as well as her practice as a biology teacher. She described her school and community as economically depressed and noted the lack of facilities made laboratory investigations difficult. Even though Lana was initially involved with a university sponsored program emphasizing student-driven research with plants, she did not implement the program at her school. Lana explained her decision not to implement student-driven research was predicated upon the demands of the current biology curriculum. Figure 23 shows the sources which informed Lana's orientation to science teaching.

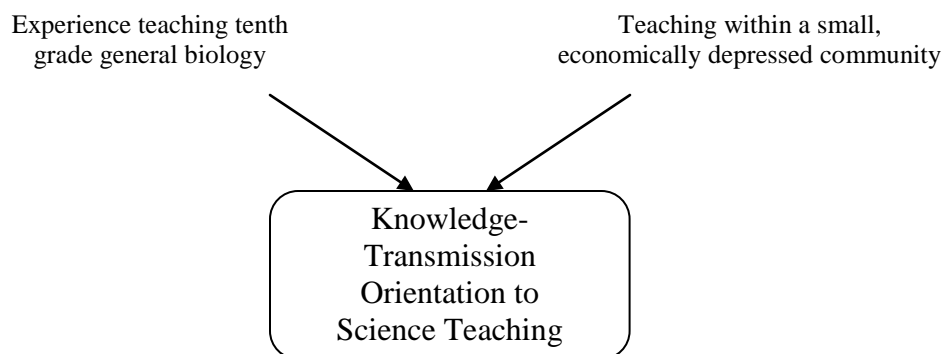


Figure 23: *Sources of Lana's orientation to science teaching*

During interviews, Lana described her ideal images of teaching as teaching biology through the 5E instructional sequence (Bybee, 1997). However, Lana's instructional sequence initially engaged students with a teacher-directed lecture focused on explanations of diffusion, osmosis, and the nature of cell membranes vocabulary. As a result, the exploration [baggie investigation] served as a validation of osmosis and diffusion rather than as an exploration. Observations of Lana's teaching on Days 1 and 2 indicated a greater reliance upon traditional strategies rather than inquiry-based instructional sequences.

Lana's orientation toward science teaching would be best described as knowledge-transmission. Teachers with a knowledge-transmission orientation to science teaching are described as relying heavily upon teacher-directed lecture as a means of explaining concepts to support student learning, rather than students learning through exploration of phenomena and actual experiences with science. Lana presented students with explanations of key terms and definitions on Day 1 during a traditional lecture. On Day 2, students completed an investigation of phenomena as a validation.

Lesson Plan

Day 1 of Lana's lesson consisted of a knowledge-transmission instructional sequence during which the lesson was initiated with a warm-up question focused on the location of membranes within cellular organelles; the lesson continued with teacher-directed explanations of phenomena and vocabulary terms. An overview of Lana's lesson plan for Day 1 is shown in Table 25.

Table 25. *Lana's lesson plan for Day 1*

Activity		Description
Warm-up question: Which one does not belong?	Engage	Teacher: <ul style="list-style-type: none">• Facilitates whole class discussion focused on warm-up question-students encouraged to collaborate on list of structures and to identify the structure which does not belong• Identifies "nucleus" as correct response
PowerPoint lecture emphasizing cell membrane structure as well as diffusion and osmosis	Explain	Teacher: <ul style="list-style-type: none">• Leads PowerPoint lecture explaining the nature of the cell membrane, diffusion and osmosis, and vocabulary• Uses a racetrack analogy to represent a cell membrane Students: <ul style="list-style-type: none">• Identify the polar and nonpolar regions of the cell membrane• Students take notes on diffusion and osmosis vocabulary
Assessment – Identify five parts of the cell membrane	Evaluate	Students: <ul style="list-style-type: none">• Respond to a simple assessment of their learning during the lesson –identify five parts of the cell membrane

Students worked independently to answer the warm-up question and shared their answers with the class. Lana identifies the nucleus as the correct response because of the nuclear membrane. Following the warm-up, Lana transitioned the lesson into a PowerPoint lecture and discussion during which she focused student thinking on cellular structures emphasizing the structure of the cell membrane. During the discussion, one student drew the cell membrane on the whiteboard and another indicated polar and nonpolar regions of the membrane. Following the discussion of membrane structure, Lana focused on how different substances pass into the membrane introducing and

explaining osmosis and diffusion. Lana ended the lesson with an assessment focused on students' retention of cell membrane structure rather than an understanding of the semipermeable nature of the membrane. Lana noted that she would read student responses but she did not intend to formally grade student work.

The lesson on Day 2 was very different from the lesson taught on Day 1 in that students conducted an investigation into osmosis and diffusion. Initially, students were engaged with a warm-up question focused on the cell theory. The students shared answers for the warm-up question with the class, identifying water, nutrients, oxygen, and vitamins as substances necessary for life which enter the cell through the membrane. Following the warm-up question, students focused on a diffusion demonstration and next, conducted an investigation into osmosis and diffusion. An overview of Lana's Day 2 lesson is shown in Table 26.

Table 26. *Lana's lesson plan for Day 2*

	Activity		Description
Day 2	Warm-up question: What must move in and out of a cell to support life?	Engage	Teacher: <ul style="list-style-type: none"> Engages students in discussion of warm-up question Students: <ul style="list-style-type: none"> Respond independently to the warm-up question and identify nutrients and water as substances passing through the cell membrane Share responses related to the structure and function of the cell membrane
	PowerPoint lecture on diffusion and osmosis	Explain	Teachers: <ul style="list-style-type: none"> Leads discussion with a series of PowerPoint slides illustrating diffusion and osmosis Students: <ul style="list-style-type: none"> Take notes and respond to questions
	Balloon demonstration - diffusion	Validate	Teacher: <ul style="list-style-type: none"> Focuses on balloon and cologne as a model for diffusion Questions students understanding of diffusion within the model <ul style="list-style-type: none"> Students: <ul style="list-style-type: none"> Use a balloon containing cologne to represent diffusion
	Baggie laboratory investigation	Validate	Students: <ul style="list-style-type: none"> Place starch solution in baggie, mass baggie, and place in iodine solution Record prediction of changes in baggie and beaker solutions

Lana implemented two representations during the lesson on Day 2. The first representation consisted of a balloon into which cologne had been placed to model diffusion through the balloon membrane. As students passed the balloon around the class, they noted the scent of the cologne as it diffused out of the balloon. Next, Lana engaged students in a discussion of diffusion focusing on the balloon and cologne. The second representation consisted of a small baggie used to represent the cell membrane and serving as the focus for an investigation into osmosis and diffusion. Students placed a starch solution in the baggie, massed the baggie and its contents, and placed the baggie in a beaker containing a distilled water and iodine solution.

A discussion of Lana's knowledge of the components of pedagogical content knowledge follows and includes a discussion of Lana's knowledge of instructional strategies, learners, curriculum, and assessment.

Knowledge of Representations and Instructional Strategies

Lana implemented several topic-specific representations into her teaching on Days 1 and 2 of the observation. On Day 1, to illustrate the nature of the cell membrane as a fluid mosaic model, she implemented an analogy of a race track as a representation for the cell membrane. Lana compared the fluidity of phospholipid molecules within the cell membrane to race cars moving around a race track. She noted that other molecules associated with the membrane such as, carbohydrate molecules, functioning as cell markers, and proteins, functioning as channels for passive and active transport, are located within the context of the membrane are also in motion within the phospholipid bilayer. Lana explained:

I want to get them to think about cell membranes. . . . It looks like a race track when we draw the phospholipids and then we will move on into the proteins and

the cholesterol. With their large cell [guided notes] they will draw in those structures. So that is what we are going to do with this. (pre-observation interview)

On Day 2, Lana implemented three representations into her lesson. First, a latex balloon was used as a representation of a semipermeable membrane. Lana explained the latex balloon represented a semipermeable membrane able to contain the air and remain inflated; however, cologne particles readily diffused through the membrane into the classroom. She explained “I usually put vanilla or cologne into a balloon and pass it around to see what happens when it is passed around the room. So there is another membrane” (stimulated recall interview, Day 1). Thus, the balloon served as both a representation of a semipermeable membrane allowing only certain substances to pass through it and as a model for diffusion in which cologne diffused out of the balloon and into the classroom to be detected by students.

Lana wanted students to understand the importance of relative concentrations of substances and the direction of osmosis and diffusion. She implemented drawings of beakers containing cells and identified the percentage of dissolved solute within the beaker and cell solutions. Next, she engaged students in a discussion focused on the direction of water movement within the model based upon the relative concentrations of dissolved solids within the two solutions to provide a concrete model of osmosis emphasizing vocabulary terms hypertonic, hypotonic, and isotonic. She explained:

I drew beakers on the board and I put cells in the beakers and I wrote hypertonic and hypotonic and isotonic and I put that the cell contained a 5 percent salt solution. So I said guys I am going to do the isotonic solution so I asked them if there were 5 percent salt then there would be 95 percent water. . . . I could come back and change the numbers and this helped them to see the difference between a hypotonic and hypertonic solutions. This really helped them to understand this concept. (pre-observation interview)

Lana drew a diagram of a cell membrane on the whiteboard to demonstrate that molecules of only certain sizes could pass through it. She explained that by creating a concrete image of a membrane she could assist students with the concept of membrane permeability. She explained:

Yes, that there are openings or ways that things can move across a semi-permeable membrane. I did not use that term and in retrospect, I wish I had. I showed them the drawing and I had small things that go through a membrane and large things that do not go through a membrane. (stimulated recall interview, Day 1)

Lana noted that through diagrams of the cell within a beaker and a cell membrane (see Figure 24), she was able to enhance student understanding of the concept of osmosis within the context of relative solute and solvent concentrations, the resulting concentration gradient, and membrane permeability.

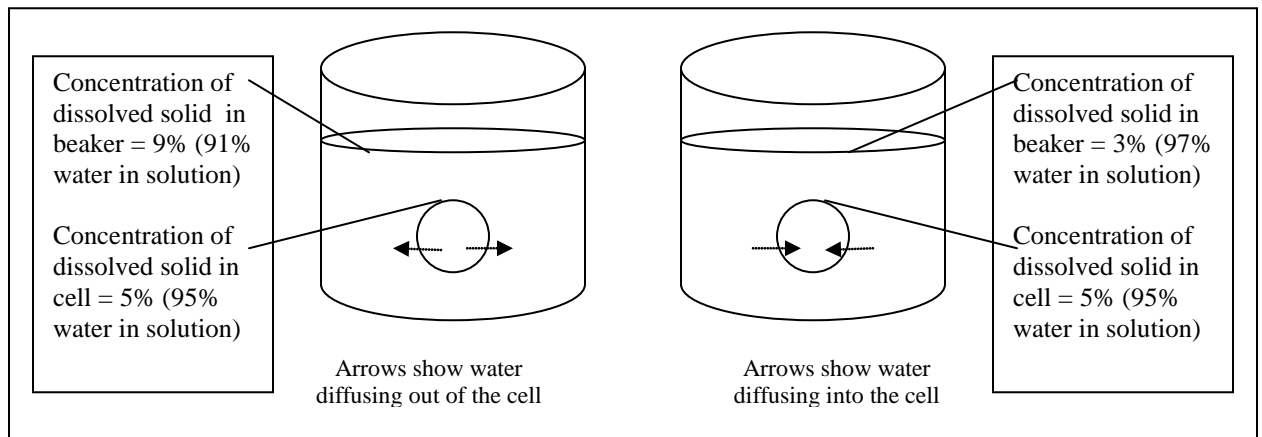


Figure 24: *Diagram illustrating direction of osmosis*

Lana implemented a baggie as a third representation on Day 2. Lab groups placed a starch solution in the baggie, massed the sealed baggie and its contents, and placed the baggie in a beaker containing distilled water and iodine. The baggie representation was an effective model of a cell and semipermeable membrane in that distilled water and iodine from the beaker solution diffused through the baggie membrane, however, starch

molecules within the baggie solution were too large to pass through the baggie and into the iodine solution within the beaker. Thus, the iodine solution in the beaker retained its amber color, while iodine diffusing into the baggie reacted with starch resulting in a color change from cloudy white to black within the baggie.

Before beginning the investigation, Lana challenged each lab group to develop a hypothesis and predict what they thought would happen to the iodine solution in the beaker and the starch solution within the baggie. She planned to discuss predictions during the following lesson and challenge students to explain their thinking. She explained:

Putting starch into a plastic bag and dropping it into an iodine solution and leave it over night. But they would predict what they think is going to happen. Again they do not necessarily know what will happen when starch and iodine are mixed, although we could show them what happens when we put starch with iodine and then we could put a starch solution into a baggie and place the baggie into an iodine solution. They could predict what will happen and they will see a reaction within 15 minutes. (stimulated recall interview, Day 1)

On the following day, Lana believed students would note a change in baggie mass and in the color of the starch solution within the baggie. She believed an increase in baggie mass, darkening of the baggie starch solution, and persistent amber coloration of the iodine solution in the beaker would be strong evidence for the direction of water and iodine movement within the model. She planned to have students draw a diagram of the baggie in the beaker using arrows to identify the direction of osmosis and diffusion. She explained:

We will go back and fine tune and we will talk about osmosis. And I am hoping, fingers crossed, that their baggies will mass out a little bit bigger. We will draw a picture of the set up. I have kids ask why we draw. Ragen asked why we draw during first hour. I said, Randy, I draw a lot with this unit. The reason that I have them draw is to put arrows on it to show which way things move. (stimulated recall interview, Day 2)

Lana believed the model would support students' understanding of the concept of a concentration gradient and the resulting direction of diffusion and osmosis based upon relative concentrations of solute and solvent within each solution. She explained:

So they will be able, I am hoping that they will be able to see that water moves across a membrane so that will lead into osmosis which is a form of diffusion. I am hoping with this that they have got diffusion with the iodine and osmosis with the water moving. (stimulated recall interview, Day 2)

Lana relied upon student generated representations to illustrate osmosis and diffusion. She explained "I ask them to draw a little model and put in little arrows which way things move and then go back to that idea" (stimulated recall interview, Day 1). She explained drawing is important because it helps students focus, process information, and develop a stronger understanding of membrane structure and function.

Lana reported her plan was to scaffold student knowledge of diffusion with the balloon demonstration, knowledge of osmosis with the cell in a beaker diagram, and the baggie lab, thus, preparing students for the decalcified egg laboratory investigation into osmosis during the following week. She explained:

Yes, they are devising their own lab investigation with their own hypothesis. If you place it [decalcified egg] in this solution, then the egg will get larger. Therefore, the solution is hypertonic or hypotonic. So that is the problem solving aspect of it for them. I would say that it is more of a lab activity. (stimulated recall interview, Day 2)

Lana's instructional strategies followed a traditional, teacher-centered approach. She relied upon a PowerPoint lecture during lessons on Days 1 and 2 to provide information about the structure and function of the cell membrane as well as key vocabulary terms including: phospholipid bilayer, polar, nonpolar, passive transport, hypertonic, hypotonic, isotonic, and concentration gradient. Exploration of concepts did not occur until Day 2 when students completed a baggie lab to investigate the diffusion of

water and iodine through the baggie membrane. However, the baggie lab followed a discussion of osmosis and diffusion in which students drew arrows on whiteboard diagrams of cells within beakers containing solutions of varying concentrations. Lana planned to build upon students' knowledge of osmosis and diffusion with an inquiry-based investigation of osmosis when decalcified chicken eggs are placed in corn syrup or distilled water.

Knowledge of Students' Understanding of Science

Lana identified students' understanding of membrane structure as a concern for students' conceptual understanding of osmosis. She explained students may have difficulty understanding the semipermeable nature of the membrane and that only small particles may pass through the membrane into the cell. Lana explained:

Yes that there are openings or ways that things can move across a semipermeable membrane. I did not use that term and in retrospect, I wish I had. I showed them the drawing and I had small things that go through a membrane and large things that go through a membrane. (stimulated recall interview, Day 1)

To focus students' thinking on membrane function, before beginning the baggie lab, Lana challenged students to predict potential changes within the baggie and beaker solutions, and identify the independent and dependent variables for the investigation. By challenging students with the baggie lab, she believed she was preparing students to draw upon their knowledge of osmosis and diffusion to generate an experimental design for a decalcified egg laboratory investigation planned for the following week. Lana began the osmosis and diffusion unit by emphasizing the importance of terminology, thus, students knowledge of vocabulary was emphasized prior to conceptual knowledge of the processes of osmosis and diffusion. Lana explained:

I am going to teach two lessons [Days 1 and 2] that relate to the cell membrane and the structure and a lead in to osmosis where the students will be doing a long term lab where they will work with eggs. We will remove the shells and put them in various solutions. I do this so that they can become familiar with the concepts of tonicity and hypertonic, isotonic, and hypotonic solutions. And this is an introduction unit. We have just completed cell structures and we are moving on to the cell membrane. (pre-observation interview)

She challenged students to predict the outcome of the baggie investigation in terms of the direction of osmosis. She noted students' ability to accurately predict the direction of osmosis was an indication of their conceptual understanding of osmosis. She explained:

Yes, I want to fine-tune their predictions and that is how we will follow up tomorrow [following the research observation cycle]. And tomorrow I am going to get into more of osmosis because I am hoping that there will be water going into the baggies too. I do not know that for sure but I think that there might be a movement of water. (stimulated recall interview, Day 2)

Lana also used diagrams and drawings to direct students' thinking about the direction of osmosis. She explained students use arrows to identify the direction of osmosis :

That is what I do quite a bit when we get into hypertonic and hypotonic. I want them to show which way the water is moving and also to show if something else is moving. I may have them use another color or label the arrows to show which way things are moving. I like to think that this helps. (stimulated recall interview, Day 2)

Concerned about the knowledge of cell membranes students bring into the lesson, Lana explained many students do not understand cell membranes exist within all cells, even plant cells in which the cell membrane is surrounded by a cell wall. She noted:

They are aware that cell membranes exist. And I was glad that they recognized that because I mentioned it several times that there are cell walls and the cell membranes are inside the cell walls. That is another misconception that kids have and I think that most of them have that idea. (stimulated recall interview, Day 1)

Lana believes biology should be relevant to students' lives to engage students and enhance their learning. She noted examples of biology are everywhere within the lives of

her students. By identifying connections between students' experiences and biology, she is able to engage students more effectively. Lana explained:

We do this cell lab which takes a good week and they do a lab write-up with it. But in between then I am going to relate to the grocery store and the water at the salad bar and the food they buy. This is probably as personal as anything. (stimulated recall interview, Day 1)

Lana explained the Day 1 lesson served as a review of membrane structure, introduction to terminology, and as a preparation for the baggie lab on Day 2. On Day 2 Lana initially engaged students with a balloon demonstration and the baggie lab, providing representations of diffusion and osmosis. Students were challenged to make and test predictions for both. Lana believes effective learning requires students to construct their understanding of concepts. Thus, Lana structured her lessons to build upon one another preparing students for the inquiry-based decalcified egg lab planned for the following week. Lana explained: "The egg investigation is another opportunity for them to elaborate and expand upon the ideas what they learned so that they get a better grasp" (stimulated recall interview, Day 2). She explained scaffolding students' knowledge of osmosis and diffusion would better prepare students to understand photosynthesis and cellular respiration to be covered later in the semester.

Knowledge of Assessment

Lana indicated she relies upon formative assessments to evaluate students' comprehension. She noted students' predictions provide insight into their prior knowledge and thinking. Before beginning the diffusion demonstration and osmosis investigation on Day 2, Lana noted she planned to have her students predict outcomes. She explained, "I tell them that they have to make a prediction of the direction of osmosis and then decide how to test it" (stimulated recall interview, Day 2).

Lana explained she challenges students to identify sources of error within laboratory investigations to gain insight into students' thinking. To identify potential sources of error, students must consider each step in the investigation and identify aspects of the protocol which could affect the results. She explained:

What were possible sources of error in the baggie investigation? It could be, I have not looked at them, but it could even go as far as some of those we may have blue water in the beaker, the baggie could have a hole in it. (stimulated recall interview, Day 2)

On Day 2, Lana drew a diagram of the a cell in a beaker of distilled water; after identifying the relative concentration of dissolved solid in the cell and the beaker, she challenged students to draw arrows to indicate the direction of osmosis. The nature of students' responses, whether water would enter or leave the cell, provided Lana with insight into their understanding of osmosis and diffusion. From this insight, Lana believed she could select effective strategies and representations to make abstract concepts understandable for students. She described this type of assessment as problem solving and essentially a performance assessment. She explained:

Yes, it will be problem solving; it is almost like a performance assessment I think. Then I have another drawing with a beaker and I might even say to them hypertonic, hypotonic, and isotonic which way would the water move? (stimulated recall interview, Day 2)

While observing student to student interactions during lessons, Lana noted she is able to evaluate understanding. Lana explained she puts students into collaborative teams of two and observes their work, listens to their explanations, questions, and comments to assess understanding. She noted:

I may put them into groups of two because of the tables. I may do that but I am not going to move tables around. I have done some serious table moving over the past few weeks to get some things to work out and get them focused. I am thinking that it might be effective to explain diffusion and osmosis. . . . They

would have to explain it; they and their partner. I think that this would be a good plan when I do osmosis. It lends itself to other things. I ask them to draw and explain what is happening. (stimulated recall interview, Day 2)

Lana indicated she would use student feedback from formative assessments as a barometer to determine students' comprehension. She explained that if student feedback indicated that students did not grasp the concept she would present it to the students in a different way before moving on. Lana explained that she planned to implement a decalcified egg investigation during the following week involving in which students would place decalcified eggs in solutions of varying concentrations to investigate osmosis. She also hoped to use the investigation as an assessment of student ability to apply their knowledge of tonicity, osmosis, and diffusion. She explained:

I am going to set up the egg lab for next week. So there might be some type of assessment while they are doing it [the egg lab]. Then while they are finishing the egg lab that will give me time to think about their understanding of these concepts. And then the final to the egg lab is usually a lab write up in which they are identifying variables and they talk about which way things moved and even develop a graph. (stimulated recall interview, Day 2)

Lana used formative assessment throughout each lesson. She believed by asking students to apply their knowledge to answer simple questions or solve problems, she could continually assess students' conceptual understanding and adapt her lesson to better meet students' learning needs. When students were engaged in the baggie lab, Lana moved from lab group to lab group posing questions and noting student responses. She explained that she paid special attention to students who she knew would struggle with the material.

Knowledge of Curriculum

Lana noted membrane structure, osmosis, and diffusion are key concepts in biology and must be understood by the students before they can fully grasp complex processes such as photosynthesis and cellular respiration. She explained:

When we get to photosynthesis and talk about the photon pump and how proteins and membranes are involved in that. . . . In cellular respiration there are proteins there too and hydrogen ions will diffuse through a membrane in the mitochondria and in the chloroplasts. The kids see the cell membranes again and again. Those are probably the two places right off hand that I can think of. (stimulated recall interview, Day 1)

When planning lessons, Lana indicated that she tries to put herself into the mindset of her students and see the lesson through their eyes. She explained that this mindset helps her design engaging and meaningful lecture/discussions, activities, investigations, and experiments for students. Lana noted that everything in biology is related in some way to osmosis. She explained:

I read an article once which explained that everything in life relates to osmosis. I am not sure that I buy into that but it is truly important for your health. It is why you gargle with saltwater when you have a sore throat. It is why you do not drink ocean water. It is why our ancestors cured hams. There are reasons that all of these things fit together. I am thinking that the whole osmosis thing I want them to see some connections with life and moving. Moving oxygen and moving other things across the membrane so the cells can maintain homeostasis. I want the kids to understand that osmosis is important for us to maintain our health. Everything is related to osmosis. (pre-observation interview)

Lana explained that she uses the Internet and high school and collegiate texts in her planning. She explained: “I also look on line; there is a lot on line. There are suggestions from other teachers about what they are doing. You can Google ‘osmosis’ or ‘diffusion’ on line and see what other teachers are doing” (pre-observation interview). Lana explained that she purposefully seeks out additional resources and does not limit herself to the textbook. She designed the lessons on Days 1 and 2 to support students’ construction of their knowledge of osmosis and diffusion. She explained:

I hope that they leave with this understanding that osmosis is important. The follow-up that you will not see is the lab that we do with the egg to show osmosis. We will take eggs, remove the shells, and place the eggs in a variety of solutions. But my students remember. They remember doing the lab and they also remember how it fits together. (pre-observation interview)

Lana spoke of the importance of the 5E instructional model and explained she tried to implement the 5E model into her instruction. However, Lana engaged students with an explanation of diffusion and osmosis prior to an exploration of the phenomena on Day 2. Lana noted the Day 1 lesson was designed as an engagement with the goal of preparing students for the exploration of osmosis and diffusion during the baggie lab on Day 2. However, Lana did not include an activity in Day 1 and essentially engaged students with a traditional lecture and discussion to prepare them for the baggie investigation on Day 2. She explained:

Tomorrow when we get to osmosis, we will circle back again and we will bring our discussion on osmosis and diffusion out again in view of what happened. So then we will elaborate on that. So they will be able, I am hoping that they will be able to see that water moves across a membrane so that will lead into osmosis which is a form of diffusion. I am hoping with this that they have got diffusion with the iodine and osmosis with the water moving. (stimulated recall interview, Day 2)

Lana noted she drew upon student knowledge of concepts related to diffusion and osmosis taught earlier in the course to scaffold student learning and make the point that processes like osmosis and diffusion do not stand alone but are interwoven throughout the fabric of biology. She explained:

I think that is the key thing with the cell membrane. It is that semipermeable barrier which allows certain things to pass and other cannot pass and we will build on that. It also ties into the cell theory and the reason I included the cell theory is because I wanted them to keep in mind that the cell is a living thing. (stimulated recall interview, Day 2)

In terms of Lana's perception of curriculum, she noted the importance of osmosis and diffusion and explained as key concepts in biology which are integral to other processes such as homeostasis, cellular respiration, and photosynthesis. The sequence of instruction was not reflective of an inquiry-based approach; Lana believed students were not prepared to explore osmosis without a lecture focused on an explanation of the concepts. She explained that the balloon activity and baggie lab were specifically designed to provide students with opportunities for students to observe the phenomena following the explanation on Day 1. Lana planned to draw upon students' understanding of osmosis during the week following the research observation cycle through an inquiry-based investigation of osmosis in decalcified eggs. Lana planned for students to formulate an experimental design, predict an outcome, and identify dependent and independent variables for the decalcified egg investigation.

Lana's PCK for Teaching Diffusion and Osmosis

The Magnusson et al. (1999) model of pedagogical content knowledge has been modified to portray Lana's knowledge for teaching (see Figure 25). As a veteran teacher, Lana's knowledge and expertise are evidenced by her subject matter knowledge as well as her knowledge of students, instructional strategies and representations, and formative assessments. She sequenced students' learning opportunities to first engage students with a lecture in which diffusion and osmosis were explained and second challenge students with a demonstration of diffusion followed by an investigation of osmosis and diffusion. Both activities served as validation of phenomena rather than explorations.

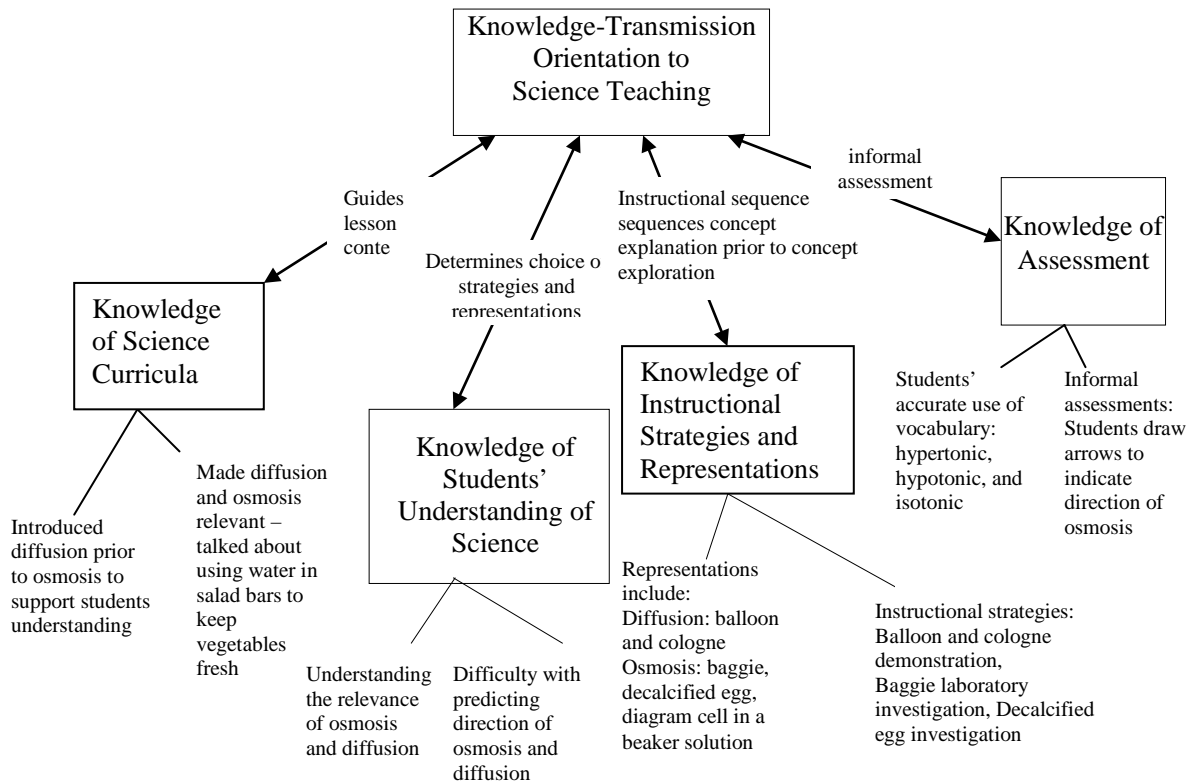


Figure 25: Lana's topic-specific PCK²⁵

The lesson on Day 1 was designed to review students' knowledge of cell membranes and introduce osmosis and diffusion through a PowerPoint lecture and discussion. On Day 2, students observed diffusion using drops of cologne within an inflated balloon and predicted the direction of osmosis and diffusion in the baggie lab. Lana explained the lessons on Days 1 and 2 were designed to prepare students for a decalcified egg in which students would be responsible for generating an experimental design, predicting outcomes, conducting the experiment, analyzing data, and developing a conclusion supported with evidence based upon their observations.

²⁵Note: Modified from Nature, sources, and development of pedagogical content knowledge for science teaching (p.99), by S. Magnusson, J. Krajcik, & H. Borko, 1999. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 95-132). Boston: Kluwer.

Lana designed representations to provide students with concrete examples of abstract concepts and incorporated them into her lessons. She noted her goal was to challenge students to apply their knowledge and explain their observations within the context of the diffusion of iodine and water along their concentration gradients in the baggie investigation. She explained:

The iodine is going across one way, so you have diffusion and water is moving across so you have osmosis. I am going to have them weigh the bags so that they have osmosis and can measure the water intake. (stimulated recall interview, Day 1)

Lana's PCK for teaching diffusion and osmosis, shown in Figure 26 represents the integration of the components of Lana's knowledge to create a form of knowledge specific for teaching diffusion and osmosis. There are four important features to note within this representation. First, Lana's orientation to science teaching is indicated in center of the model indicating the centrality of her orientation to her teaching. Lana's orientation to teaching science, described as knowledge-transmission, acts as a filter influencing the interpretation and integration of the other components of Lana's PCK. Second, reciprocating arrows between the components of PCK and Lana's orientation indicate the influence these aspects of her PCK have upon one another. Her orientation to science teaching interprets the components of her PCK which, in turn, shape her orientation. Third, arrows connecting the components of Lana's PCK components indicate the highly integrated nature of her PCK. The components of PCK inform and influence one another. Fourth, brief connecting statements between components provide insight into the rationale for Lana's integration of components for teaching diffusion and osmosis.

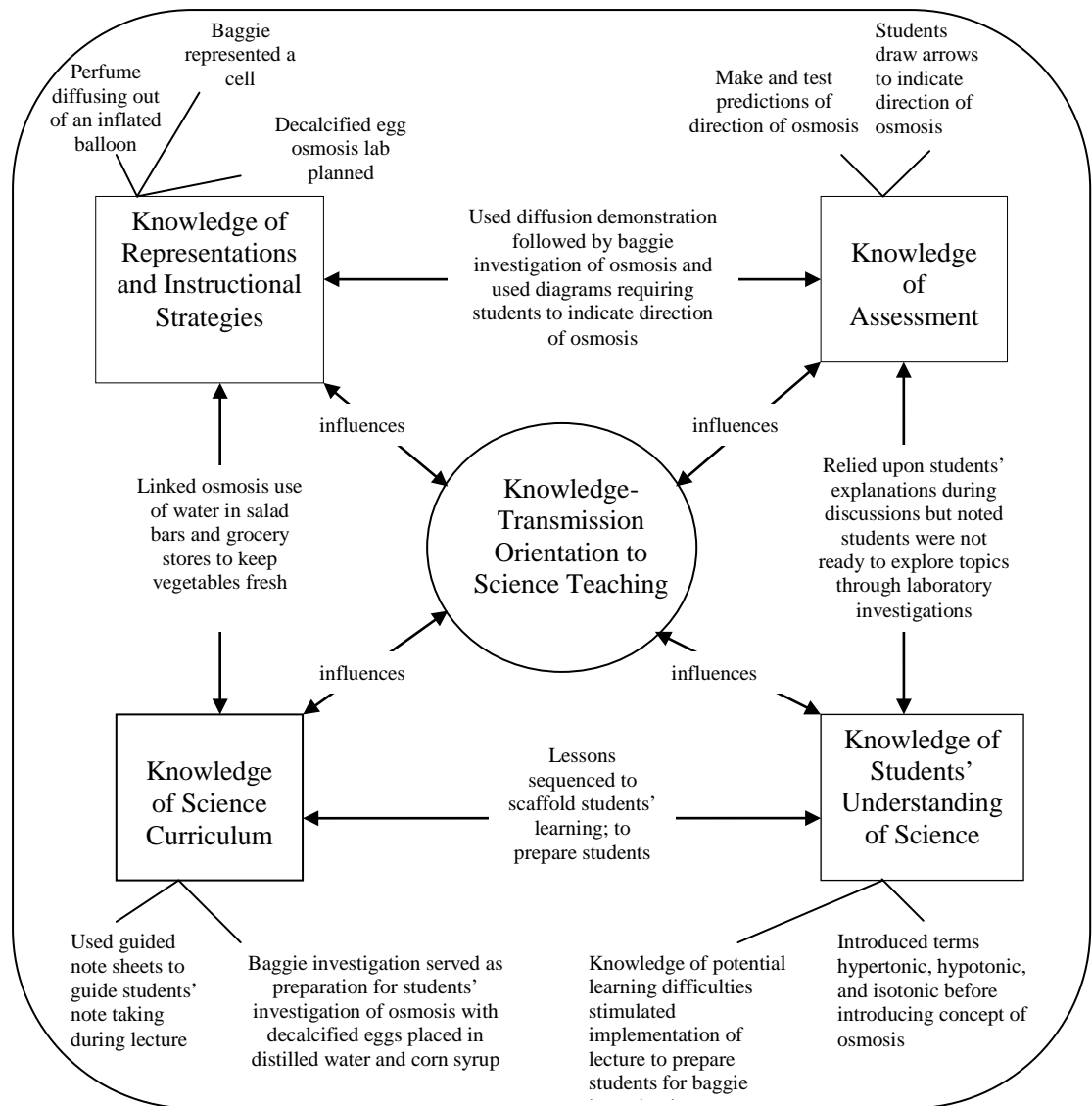


Figure 26: *Integration of Lana's topic-specific PCK*

Because Lana believed students would have difficulty predicting the direction of water movement during osmosis, she prepared students for the baggie investigation on Day 2 with a lecture focused on membrane structure and diffusion of substances across the membrane from high to lower concentrations. To gauge students' comprehension, Lana challenged student to make and test predictions and draw arrows to identify the direction of osmosis in representations of cells within solutions of varying concentrations.

Lana believed students were not prepared to carry out investigations without preparation. Hence, she provided support and guidance for students through a PowerPoint lecture on Day 1 to prepare them for an exploration of osmosis and diffusion on Day 2. Lana integrated all PCK components during planning and teaching, however, Lana believes her students are not ready for inquiry, hence, she placed greater emphasis upon explanations through lecture and discussion rather than student exploration of concepts.

Content Representation

In Table 27, a Content Representation (CoRe) illustrates Lana’s knowledge of teaching. The components of PCK are represented within the context of the CoRe and specific examples of instructional strategies and representations, assessments, potential student difficulties, and curricular considerations are included. When reading the CoRe, it is important to read individual columns (e.g. Big Idea A) from the top to the bottom vertically. The columns extend beyond a single page.

Table 27. *Content representation for Lana*²⁷

Content Representation (CoRe)			
Considerations	Big Idea A	Big Idea B	Big Idea C
	Membranes are semi-permeable and only allow certain substances to pass through into the cell.	Diffusion occurs when substances move from higher concentrations to lower concentrations.	Semi-permeable membranes maintain stability inside cells while external conditions change.
Identify the learning goals for students within this lesson?	Plasma membranes are semi-permeable and allow only some things to enter the cell. All nutrients must pass through the membrane to enter the cell.	Water is necessary for all life and must enter the cell through the semi-permeable cell membrane. Water diffuses through pores in the membrane from higher to lower concentrations.	Only some materials will be able to pass through a membrane and enter the cell. Cellular contents are unique and different from the environment in which the cell is found.

<p>Why is it important for students to know this content? <i>[Knowledge of curriculum]</i></p>	<ul style="list-style-type: none"> • It is important for students to understand how things fit together in biology. • The concept of the cell membrane is an important because all cells have cell membranes. 	<ul style="list-style-type: none"> • Diffusion is a biological concept which is found throughout biology. • Substances diffuse from higher to lower concentrations. 	<ul style="list-style-type: none"> • The cell membrane supports life by limiting what can enter the cell and maintaining a unique internal cellular environment. • Diffusion and osmosis are key concepts in biology.
<p>Identify potential student difficulties and limitations associated with teaching this idea. <i>[Knowledge of students as learners]</i></p>	<p>Potential learning difficulties may be:</p> <ul style="list-style-type: none"> • understanding the structure of the cell membrane. • understanding the nature of the cell membrane in terms of the life and function of he cell. • developing a prediction for the balloon demonstration and the baggie investigation. 	<p>Potential learning difficulties may be:</p> <ul style="list-style-type: none"> • explaining how substances necessary for life (water, carbohydrates, lipids, etc.) enter the cell through the cell membrane. • understanding the diffusion of substances from greater to lesser concentrations. 	<p>Potential learning difficulties may be:</p> <ul style="list-style-type: none"> • understanding terminology associated with osmosis: <ul style="list-style-type: none"> • hypertonic, hypotonic, and isotonic. • connecting the processes of osmosis and diffusion to living cells. • explaining the concept of a concentration gradient. • relating concentration gradient to direction of osmosis and/or diffusion.
<p>Teaching strategies and representations implemented and particular reasons for using these strategies to engage students with this idea. <i>[Knowledge of instructional strategies and representations]</i></p>	<p>Representations:</p> <ul style="list-style-type: none"> • representation of the cell membrane as a race track. • cologne diffuses through latex membrane of balloon. • water and iodine diffuse through baggie membrane resulting in a color change of starch solution. <p>Instructional strategies:</p> <ul style="list-style-type: none"> • lecture/discussion, • questions, and • balloon demonstration. 	<p>Representations:</p> <ul style="list-style-type: none"> • the scent of cologne becomes apparent in classroom as it diffuses through the balloon latex membrane. • change in baggie mass as water and iodine diffuses into the bag. • iodine causes a color change in the baggie; there is no color change in the beaker solution. <p>Instructional strategies:</p> <ul style="list-style-type: none"> • students pass a balloon containing drops of cologne around the classroom and as the cologne diffuses through the latex wall of the balloon, the scent of the cologne is detected. • Students predict direction of osmosis and diffusion in baggie lab. • Students test predictions. 	<p>Representations:</p> <ul style="list-style-type: none"> • baggie membrane allows water and iodine to pass through it but does not allow starch to pass. • iodine acts as an indicator providing evidence of osmosis and diffusion as iodine and water diffuses into baggie. • iodine in the beaker solution retains amber color indicating the absence of starch outside of the baggie. <p>Instructional strategies:</p> <ul style="list-style-type: none"> • explanation of concepts through lecture and discussion prior to exploration. • students make and test predictions concerning the direction of diffusion and/or osmosis in baggie lab. • Students will conduct a decalcified egg investigation to investigate osmosis and diffusion occurring within the egg when placed in solutions of varying concentrations.

<p>Identify ways of ascertaining that students concepts taught. [<i>Knowledge of Assessment</i>]</p>	<ul style="list-style-type: none"> • As a warm-up activity, students are asked to identify five things required for cell life that pass through the cell membrane. 	<ul style="list-style-type: none"> • Students are asked to explain why they can detect an odor when a balloon containing cologne is passed around the class. • Exit slips are completed by students-identifying structure of the cell membrane. 	<ul style="list-style-type: none"> • Students predict changes within the baggie - nature of predictions provides insight into students' comprehension. • Teacher questioning students to assess comprehension of key concepts. • Students record observations and data taken from laboratory investigations in their notebooks. The notebooks are graded on a regular basis to assess student comprehension.
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The CoRe captures Lana's PCK for teaching diffusion and osmosis and also describes her teaching practice. Her reliance upon teacher-directed lecture as a means of transmitting knowledge to her students is evident.

²⁷Note: Modified from *Understanding and developing science teachers' pedagogical content knowledge*, by J. Loughran, A. Berry, and P. Mulhall, 2006, p. 28. Rotterdam: Sense Publisher.

CHAPTER FIVE: CROSS-CASE ANALYSIS

In this chapter, I present assertions based upon the full data set presented in the six case profiles in Chapter Four. The assertions describe major themes observed across the cases and are organized around the sub-research questions which guided this study. The overarching research question guiding this study was: When teaching lessons on osmosis and diffusion, how do experienced biology teachers draw upon their topic-specific pedagogical content knowledge?

Sub-Research Questions

To answer this question, I developed the following sub-questions:

1. What are the nature and sources of the experienced biology teachers' orientation to science teaching? (Assertion 1)
2. What is the nature of experienced biology teachers' knowledge of representations and instructional strategies and how does this knowledge inform their teaching practice? (Assertion 2)
3. What is the nature of experienced biology teachers' knowledge of students' understanding of science and how does this knowledge of science learners inform their teaching practice? (Assertion 3)
4. What is the nature of experienced biology teachers' knowledge of formative assessment strategies and how does this knowledge inform their teaching practice? (Assertion 4)
5. What is the nature of experienced biology teachers' knowledge of biology curriculum and how does this knowledge inform their teaching practice? (Assertion 5)

6. In what ways do experienced teachers integrate the topic-specific components of their pedagogical content knowledge when teaching osmosis and diffusion?
(Assertion 6)

When supporting each of the six assertions, I refer to the case profiles and reference relevant data from the interviews, classroom observations, and researcher field notes. This data was used to understand the nature of experienced biology teachers' topic-specific pedagogical content knowledge and how this knowledge influenced participants' teaching of osmosis and diffusion.

Assertions

Assertion 1: The majority of the participants held constructivist orientations to teaching science. Reflection on their high school biology teaching experience and extensive knowledge of their students and specific school context were the primary sources of their science teaching orientations.

Overview of Orientations for Teaching Biology

Magnusson et al. (1999) define orientation to science teaching as representing “a general way of viewing or conceptualizing science teaching” (p. 97). Nine orientations to science teaching including: “process, academic rigor, didactic, conceptual change, activity-driven, discovery, project-based, inquiry, and guided inquiry” (p. 100-101) were proposed by Magnusson et al. (1999). When analyzing the data, I found Magnusson et al.'s (1999) nine orientations to be limiting in terms of understanding the nature and sources of the teachers' orientation to science teaching. The descriptions for each orientation provided minimal insight into teacher thinking and beliefs about teaching, learning, and learners. To develop a better understanding of teacher orientations, I drew upon the work of Brown (2008) and Brown, Friedrichsen, and Abell (2008). These researchers described orientation to science teaching as complex and identified five

dimensions of teachers' orientations to science teaching including: (1) goals and purposes for teaching biology, (2) perception of teacher role, (3) perception of students' role, (4) ideal images of teaching, and (5) perception of science as a discipline.

Nature of Teachers' Orientation to Science Teaching

A cross-case comparison of the participants in this study revealed five of the six teachers held a constructivist orientation to science teaching. These teachers emphasized the importance of an active role for students in learning and believed students learn most effectively through explorations of phenomena. The teachers supported students' construction of a conceptual framework based upon the following foundational concepts: (a) the structure and function of semipermeable cell membranes, (b) the importance of water in living systems, (c) the nature of homeostasis, and (d) random molecular motion as the driving force for diffusion and osmosis. During interviews, these teachers explained the importance of constructing a framework of knowledge to help students make sense of new ideas, such as, the forces determining the direction of osmosis (e.g., molecular motion, tonicity, and concentration gradient). The teachers implemented representations and explorations to support the construction of this framework of knowledge among their students. The teachers actively engaged students in learning through explorations of diffusion and osmosis. The teachers supported students' conceptual understanding of diffusion and osmosis by drawing upon students' observations and experiences with the phenomena to construct explanations. Students were challenged to apply their knowledge of diffusion and osmosis to new scenarios and support their explanations with evidence. Hence, I describe Emma, Cathy, Janis, Jason, and Kacy as holding a constructivist orientation to science teaching.

I describe Lana's orientation to science teaching as a knowledge-transmission orientation. Evidenced by a traditional approach to instruction, teachers holding a knowledge-transmission orientation to science teaching engage students with lecture and teacher explanations of phenomena and use laboratory investigations as validation rather than as explorations. Lana believed her students were unprepared to conduct explorations and used teacher-directed lectures to explain the nature of semipermeable membranes, the processes of diffusion and osmosis, as well as the importance of homeostasis in living systems. Lana's instructional sequence differed from the other teacher in that she initially presented information to students through a teacher-directed lecture and used the laboratory investigation as a validation. In the following section, I delve more deeply in each of the dimensions of the orientation to science teaching.

Dimensions of Teacher Orientation

Overview. The five dimensions of science teaching orientation included the following: (1) goals and purposes for teaching science, (2) perception of teacher's role in student learning, (3) perception of students' role in learning, (4) ideal images of teaching science, and (5) perception of science as a discipline. Of the five dimensions, the least useful was the ideal images of science teaching. This dimension did little to enhance understanding of the orientation to science teaching held by the experienced teachers participating in this study.

Goals and purposes for teaching science. The goals and purposes for teaching biology informed the approach to science teaching implemented by the teacher. Emma, Janis, Jason, Cathy, and Kacy identified actively engaging students in explorations of phenomena and encouraging students construct their knowledge from experiences

phenomena as an overarching goal for teaching science. The teachers wanted their students to think critically, find answers to questions, and construct their knowledge of biology from their experiences. Lana identified her goal for teaching biology as enhancing students' understanding of life and the realization that all concepts in biology are connected. Hence, there are important differences in the goals for teaching biology held by the participants in this study. For example, the goal for students to construct their knowledge of biology from their experiences with investigations of phenomena led the teachers to engage students initially with an exploration, focusing on students' actions involved in the construction of their knowledge. In comparison, Lana's goal emphasized students' learning in terms of their understanding of content knowledge and their perception of biological concepts as interconnected. Hence, the goals for teaching biology identified by Emma, Cathy, Janis, Jason and Kacy are focused on students' thinking and their approach to learning (e.g., actively constructing knowledge, asking and answering questions) whereas, the focus of Lana's goals for teaching biology are focused on students' knowledge of biological content rather than the pathway to achieve understanding (e.g., critical thinking, constructing knowledge)

Perception of teacher role. Janis, Jason, Emma, Cathy, and Kacy reported that reflection on their experience with teaching general biology changed their perception of teacher and students' roles in teaching and learning. They progressed from a teacher-centered, knowledge-transmission approach early in their practice to a student-centered, constructivist instructional approach. The teachers believed students learned most effectively when actively engaged in explorations of phenomena. Their teaching focus was on stimulating students' thinking about patterns in biology, asking and answering

questions, developing explanations based upon their experiences, and supporting claims with evidence. The teachers implemented an implicit 5E (Bybee, 1997) instructional model to support students' learning through their experiences and explorations of scientific concepts. Next, the teachers challenged students to apply their knowledge to explain novel scenarios. Lana described her teacher role as a facilitator; however, during classroom observations her actions told a different story. She was focused on presenting content to students through teacher-directed lectures and used laboratory investigations as a validation rather than an exploration of concepts.

Perception of student role. Noting their goal to support students' construction of biological knowledge, Emma, Cathy, Janis, Jason, and Kacy held the belief that students learn most effectively from their experiences with the phenomena. The teachers described the student role as that of an active participant, constructing their knowledge of biology through explorations of phenomena, making and testing predictions, and generating explanations based upon their experience and observations. Lana believed students were not prepared to conduct explorations and engaged students with traditional lecture, providing explanations of the phenomena prior to explorations and used investigations as a validation of the concepts. Hence, Lana's beliefs about students' role in learning constrained her implementation of a 5E (Bybee, 1997) instructional model even though this was identified as one of her overarching goals for teaching biology.

View of science as a discipline. The view of science as a discipline held by the teachers provided important insight into their overarching orientation to science teaching. Emma, Cathy, Jason, Janis, and Kacy perceived science as way of knowing that required empirical evidence. The teachers required students to use evidence to support claims and

conclusions. Hence, the teachers perception of science as a discipline is evidenced in their instructional approach and their constructivist orientation to science teaching.

Lana perceived science to be more closely aligned to knowledge explaining the the natural world, instead of exploring the natural world to gain an understanding of life and supporting conclusions with evidence. An overview of participants' orientation in terms of the five dimensions is shown in Table 28.

Table 28: *Dimensions of teachers' orientation to science teaching*

Dimensions of Teacher Orientation	Teachers					
	Cathy	Janis	Jason	Emma	Kay	Lana
Goals and purposes for teaching biology	To construct knowledge of biology by investigating biological concepts.	To construct knowledge of biology by investigating concepts in biology.	To construct knowledge through investigation and problem-solving.	To construct knowledge of biology and support problem solving.	To construct knowledge of biology by investigating biological concepts.	To understand the relevance of biology to life.
Perception of teacher role	To be flexible, sensitive and responsive to students' learning needs.	To use effective representations and investigations to scaffold students' learning.	To be a caring adult and model effective learning strategies for students.	To challenge students to think critically and solve real-world problems.	To challenge students to apply their knowledge to novel scenarios.	To be a facilitate learning by engaging students in relevant activities.
Perception of students' role	To be open to using different learning strategies.	To assume personal responsibility for learning.	To be open to new ideas and be prepared to learn.	To be an active participant in learning.	To be prepared to learn and to work hard.	To be responsible for their own learning.
Ideal images of science teaching	Supporting students' construction of science knowledge.	Supporting students' construction of science knowledge.	Supporting students' construction of science knowledge with technology.	Engaging students with the 5E instructional model.	Aligning instruction with learning targets.	Engaging students with ecological, problem-solving activities.
View of science as a discipline	Perceives science as relying upon investigation and empirical evidence.	Perceives science as relying upon empirical evidence derived from investigation.	Perceives science as relying upon empirical evidence derived from investigation	Perceives science as relying upon empirical evidence derived from investigation.	Perceives science as relying upon empirical evidence derived from investigation	Perceives science as a way for students to understand the natural world.

In summary, using five dimensions to analyze data and define teacher orientations enabled me to understand and explain the differences in orientations observed among the teachers from multiple perspectives. I was able to make connections between the orientation to science teaching held by the teachers and their beliefs about teaching, learning, and learners. It would be very difficult to explain Lana's orientation in the absence of the dimensions.

Sources of Teacher Orientation to Science Teaching

The sources of teacher orientation to science teaching include experiences which inform the teachers' goals for science teaching, their perception of teacher's and students' roles in learning, and the perception of science as a discipline. In the following sections, I describe and explain the sources of participants' orientation to science teaching.

Teaching experience. All six teachers were experienced in teaching general biology to tenth grade students. Teaching experience of the participants ranged from seven to nineteen years. Lana, Cathy, Emma, and Jason taught in small, rural high schools, whereas, Janis and Kacy taught in large suburban high schools. All six teachers identified their teaching experience and their reflection on that experience as having a strong influence on their goals and purposes for teaching biology, their perceptions of teacher and students' roles in teaching and learning, and their views of science as a discipline. The teachers noted reflection on their practice and students' learning played a major role in their approach to teaching biology. All six teachers identified both successes and failures in their teaching and students' learning. During the stimulated recall interviews following each observation on Day 1 and 2, the teachers noted changes

they planned to make when teaching diffusion and osmosis in the future to better support students' learning.

Professional Learning Teams. Janis, Cathy, and Kacy identified professional interaction with colleagues through a Professional Learning Team (PLT) as having an important influence on their planning and teaching. The teachers noted their involvement with a PLT was critical for developing a common curriculum for tenth grade biology; generating common representations, investigations, and demonstrations; as well as designing common formative and summative assessments (e.g., rubrics, quizzes, chapter tests, semester exams) for each unit. The teachers noted the PLT analyzed common assessments to identify student learning difficulties with content and the most effective representations, demonstrations, and investigations. Emma did not have access to a PLT within her school but made connections with other teachers through PREP.

Partnership for Research and Education with Plants. Emma, Janis, Cathy, and Lana participated in a university program, Partnership for Research and Education with Plants (PREP). PREP supports partnerships between teachers and plant research scientists for the implementation of student-driven research into high school biology. Emma, Janis, and Cathy were actively engaged in PREP; the teachers attended three workshops per year and supported students with the development of independent research projects investigating environmental influences on plant growth. Students had access to wild-type and mutant *Arabidopsis* seeds through plant research scientists. Through the PREP program, teachers interacted with plant research scientists to support student driven research investigating the affect of environmenal conditions on the growth of wild-type and mutant *Arabidopsis* plants to gain insight into the role of previously uncharacterized

genes. Although, Jason and Kacy were not involved with PREP, each emphasized explorations of phenomena and students' use of evidence to support explanations. Therefore, the PREP experience helped them view science the development of new scientific knowledge as claims based on empirical evidence.

Summary

This study examined teachers' orientation to science teaching through the dimensions identified by Brown (2008) and Brown et al. (2008). The dimensions provided important insight into teacher thinking within the context of their goals and purposes, perception of teacher and students' roles in learning, and their perception of science as a discipline. Janis, Cathy, Jason, Emma, and Kacy held constructivist orientations and believed students learn from their experiences during explorations of phenomena and engaged students with an implicit 5E (Bybee, 1997) instructional model, describing their role as facilitators. The teachers engaged students with explorations of phenomena and supported students' construction of biological knowledge. The teachers' beliefs about teacher and students' roles in learning informed their constructivist orientation to science teaching. Lana demonstrated a knowledge-transmission orientation to science teaching informed by her beliefs about teacher's and students' roles in learning. She placed students in the role of passive learners in a teacher-directed learning environment.

The perception of science as a discipline was reflective of the teachers' orientation to science teaching. Emma, Cathy, Jason, Janis, and Kacy perceived science as a discipline in which new knowledge was generated through scientific investigations and supported with empirical evidence. Their constructivist orientation is reflective of

their perception of science. Whereas, Lana's knowledge-transmission orientation to science teaching is reflective of her perception of science as a body of interconnected knowledge explaining the nature of life in the natural world.

Assertion 2: The teachers used representations at the molecular, cellular and plant organ levels which served as the foci for demonstrations, analogies, and student investigations. The majority of the teachers sequenced their instruction to have students explore the phenomena of diffusion and osmosis prior to constructing explanations through teacher-led interactive lectures.

The case profiles show that all six teachers implemented topic-specific representations for osmosis and diffusion. All teachers engaged students with the phenomena of diffusion and/or osmosis using representations which included: balloons and cologne, food dye and water, dialysis tubing, baggies, potato slices, decalcified chicken eggs, *Elodea* leaf cells, lettuce leaves, and Fast Plants. The representations served as foci for demonstrations or investigations. Students made and tested predictions about the direction of diffusion and/or osmosis and drew upon their knowledge of osmosis and diffusion and observations to interpret and explain the outcomes of demonstrations and investigations. Emma, Janis, Cathy, Kacy, and Jason engaged students with the phenomenon of diffusion and/or osmosis through demonstrations or investigations prior to developing explanations based upon students' observations during teacher-led interactive lectures. In the following sections I explain the nature of representations of cells including living, artificial, and virtual cells as well as plant organs including lettuce leaves, potato slices, and Wisconsin Fast Plants. Table 29 provides an overview of the representations and instructional strategies used by teachers for teaching osmosis and diffusion.

Table 29. *Representations and instructional strategies implemented by participants*

		Representations		Teachers			
		Emma	Janis	Cathy	Kacy	Jason	Lana
D I F F U S I O N	Predictions	Yes		Yes	Yes		Yes
	Food dye in water	Demonstration		Demonstration	Demonstration		
	India ink in water			Demonstration			
	Cologne in balloon						Demonstration
Predictions		Yes	Yes	Yes	Yes	Yes	Yes
O S M O S I S	C E L U L A R	<i>Elodea</i>		Investigation			
		Decalcified Egg	Investigation		Demonstration		Investigation
		Dialysis tubing		Investigation			Investigation
		Baggie			Investigation		Investigation
	M O L E C U L A R	MoLo Animation		Demonstration	Demonstration	Demonstration	Demonstration
		Analogy of Blindfolded students		Yes	Yes		
		<i>Osmo-beaker</i> computer program					Investigation
	P L A N T	O R G A N S	Lettuce leaves			Investigation	
			Potato slices	Investigation	Investigation		
			Fast Plants	Investigation			

The teachers implemented teacher demonstrations and laboratory investigations as instructional strategies to support students' conceptual understanding of diffusion and osmosis. It is important to note the demonstrations were followed by investigations. Challenging students to make and test predictions was a persistent theme noted throughout the practice of all six teachers.

Diffusion

Lana, Cathy, Kacy, and Emma introduced the concept of diffusion prior to osmosis. The teachers engaged students with demonstrations in which students were challenged to predict changes resulting from diffusion occurring within liquids and gases. Emma, Cathy, and Kacy used the diffusion of food dye in a beaker of water at room temperature. Prior to placing drops of food dye in water, Emma, Cathy, and Kacy challenged students to predict changes in the food dye and water over time. Next, students tested their predictions by observing changes in the solution. Cathy also referenced a representation involving a droplet of India ink placed in a drop of water on a microscope slide. She explained heat from the microscope bulb would increase the molecular motion of India ink and water causing diffusion to occur rapidly. Cathy and Janis implemented an analogy of blindfolded students moving randomly in the classroom as a representation of diffusion resulting from random molecular motion. Lana implemented a representation of the diffusion of gases in which several drops of cologne were placed in a balloon. Next, the balloon was inflated and students were challenged to make predictions about the diffusion of cologne through the latex balloon membrane before passing the balloon among the students. Later in the lesson, Lana drew upon students' observations of the diffusion of the balloon membrane as a semipermeable membrane allowing the cologne scent to diffuse through the membrane while the balloon remained inflated. An overview of teacher representations for diffusion is shown in Table 30.

Table 30. *Representations of Diffusion.*

Representation: Diffusion		
	Description	Diffusion
Food Dye and Water	Several drops of food dye are placed in a beaker of water at room temperature.	Food dye diffuses through the water forming a solution of uniform color; the process occurs slowly.
India ink and water	A single drop of India ink is placed in several drops of water on a microscope slide.	Heat from the bulb increases the kinetic energy of the system resulting in rapid molecular motion and diffusion of the ink in the water.
Balloon and cologne	Several drops of cologne are placed in a balloon which is then inflated by the teacher and passed among the students.	Cologne diffuses through the balloon into the classroom, however, the balloon remains inflated. Students detect the scent while passing the balloon.
Analogy	Blindfolded students crowded into a classroom, moving randomly and colliding with other students to move from areas of higher to lower congestion.	This analogy focuses students upon the random molecular movement as the driving force for diffusion. Random motion and collisions result in the gradual movement from areas of higher congestion to areas of lower congestion.

To understand diffusion and osmosis (the diffusion of water through a semipermeable membrane) all the teachers believed students must perceive random, molecular motion as the driving force for both diffusion and osmosis. Janis, Jason, Cathy, Kacy, and Emma used animations from Molecular Logic (Concord Consortium, 2009) as representations for diffusion. The animations illustrated random motion and collision of molecules as the driving force for diffusion. To underscore students' understanding of the role of random molecular motion in both diffusion and osmosis, Cathy and Janis used an analogy of blindfolded high school students (see Table 30) moving randomly, colliding with one another, and gradually moving from areas of greater congestion to areas of lesser congestion within the classroom. Cathy and Janis used this analogy to make a connection between random motion and collisions among blindfolded students with random motion and collisions of molecules. Only Cathy referenced the effect of heat upon kinetic energy, molecular motion, and the rate of diffusion.

Representations at the Cellular Level

The teachers used multiple representations of cells in which osmosis and/or diffusion were observed. Living representations of cells included microscopic

observations of cells within *Elodea* leaves and decalcified eggs. Non-living cellular representations included dialysis tubing and baggies. All six teachers used cellular representations as foci for demonstrations or investigations into osmosis and/or diffusion. In the following sections, I identify and explain the representations for teaching diffusion and osmosis implemented by the teachers.

Plant cells within Elodea leaves. Janis used *Elodea* leaf cells as living representations for osmosis. Students used microscopes to observe changes in cells after placing drops of distilled water or a saline solution on *Elodea* leaves on microscope slides. An overview of the *Elodea* cell representation is shown in Table 31.

Table 31. *Living cells as representations for osmosis.*

Representation: Cells in <i>Elodea</i> Leaves		
External Environment	Direction of Net Water Movement	Evidence of Osmosis
Distilled Water	Water enters cells within <i>Elodea</i> leaf.	<i>Elodea</i> cells swell; contractile vacuole enlarges.
Saline Solution	Water leaves cells within <i>Elodea</i> leaf.	<i>Elodea</i> cells shrivel within cell wall; contractile vacuole shrinks and the plasma membrane pulls away from the cell wall.

Janis noted her goal in using *Elodea* leaf cells was to emphasize the direction of osmosis within the cells resulting from exposure to distilled water or a concentrated saline solution. Students observed changes within the central vacuole of the cells with exposure to distilled water or saline.

Decalcified chicken eggs. Emma and Kacy used decalcified chicken eggs as representations for living cells undergoing osmosis. Egg shells were dissolved when eggs were placed in vinegar for a period of 24 hours, leaving the eggs surrounded by a semipermeable membrane allowing only water to enter or leave the cell. An overview of the decalcified egg representations is shown in Table 32.

Table 32. *Decalcified chicken eggs as cell and membrane representations*

Representation: Decalcified Chicken Eggs as Representations of the Cell		
External Environment	Direction of Osmosis	Evidence of Osmosis
Distilled Water	Water enters egg	Increase in mass of egg
	Egg swells	Increase in size of egg
	Egg gains mass	Membrane is stretched
Corn Syrup	Water leaves egg	Decrease in mass of egg
	Egg shrivels	Decrease in size of egg
	Egg loses mass	Membrane shrived

The teachers varied in their use of decalcified eggs ranging from a demonstration to a cookbook laboratory to an open-ended inquiry investigation. Kacy engaged students in a teacher demonstration of osmosis. First, Kacy challenged students to predict changes to the decalcified egg before placing the egg in corn syrup. Forty-eight hours later, during the following lesson, students observed and touched the egg to note changes and test their predictions. Emma engaged students with a cookbook investigation of osmosis in decalcified eggs. Student predicted the direction of osmosis for the eggs prior to massing and placing the eggs in distilled water or corn syrup. Students tested their predictions 24 hours later, when observations of changes in the appearance and mass of the eggs were made. Lana planned to have students design their own inquiry-based investigations with decalcified chicken eggs during the week following the research observation cycle. She asked students to develop a hypothesis for their investigation, identify variables, predict changes within the eggs, and design an investigation protocol including the environments in which the eggs would be placed.

Emma used the decalcified egg as a student investigation because she wanted students to conduct a hands-on investigation into osmosis. She did not plan for students to investigate osmosis within plant organs (e.g., potatoes or lettuce leaves). She used decalcified eggs because the eggs underwent dramatic changes in mass and appearance

after being placed in corn syrup or distilled water for 24 hours. Kacy utilized the decalcified egg representation as a teacher demonstration instead of a student investigation because of time constraints. She believed the demonstration provided supporting evidence for students' understanding of the direction of osmosis from areas of higher to lower concentrations, and noted students were able to see dramatic changes in the egg after placement in corn syrup. When eggs were placed in corn syrup, water moved from an area of higher water concentration within the egg into an area of lower water concentration within the corn syrup. The reverse was true when the eggs were placed in distilled water. Emma, Kacy, and Lana noted decalcified eggs provided students with excellent representations of osmosis because of significant and obvious changes in the eggs' mass and appearance.

Artificial cell models. Jason and Cathy used dialysis tubing as a representation of the cell and cell membrane to investigate diffusion and osmosis. Both teachers directed students to fill the dialysis tubing with a starch and glucose solution and predict changes to the dialysis tubing solution following placement in a beaker containing water and iodine. Students tested predictions by observing color changes within the dialysis tubing and tested for the presence of glucose within the beaker solution. Both teachers noted that glucose diffused out of the tubing and into the solution in the beaker, while iodine and water diffused into the dialysis tubing. The dialysis tubing representation allowed students to observe the diffusion of substances along their concentration gradient both into and out of the artificial representation of a cell.

Kacy and Lana used plastic baggies as a representation for a cell and semipermeable membrane. The teachers noted the baggie investigation provided obvious

results for the direction of osmosis and the diffusion of iodine. Both teachers noted cost as the major reason for using baggies rather than dialysis tubing as cellular representations. Both teachers indicated that inexpensive store brands of baggies are excellent replacements for dialysis tubing. An overview of the artificial cell models and semipermeable membrane representations is shown in Table 33.

Table 33. *Artificial cell models and semipermeable membrane representations*

Representation: Artificial cell and semipermeable membrane						
	Contents	External Environment	Diffusion	Osmosis	Direction	Evidence
Dialysis tubing	water, glucose, and starch solution	iodine and distilled water	Glucose		Out of cell	Positive glucose test
			Iodine		Into cell	Color change
				Water	Into cell	Size/mass increase
Baggie	water and starch solution	iodine and distilled water	Iodine		Into cell	Color change
				Water	Into cell	Size/mass increase

Dialysis tubing and baggies provided students with an opportunity to observe osmosis and diffusion within the context of an artificial cell and membrane and test predictions for the direction of osmosis and diffusion. The baggie and dialysis tubing models reduce teacher preparation time as the chicken eggs must be decalcified in vinegar 24-hours prior to use in student investigations or teacher demonstrations.

Virtual cell models. Jason was the only participant to implement technology as a means for students to explore the concept of osmosis. The *Osmobeaker* computer program (Meir, Stal, & Maruca, 2004) allowed students to manipulate the concentration of dissolved solid within a virtual IV solution and predict resulting direction of osmosis in a virtual red blood cell. An overview of the virtual cell model is shown in Table 34.

Table 34. *Virtual representations of a red blood cell and IV solution*

Representation: Virtual cell model for osmosis		
Representation	Direction of Net Water Movement	Evidence of Osmosis
Virtual red blood cell (RBC) in IV solution with low salt content [hypotonic environment]	Water from IV solution moves into the RBC.	RBC enlarges as water enters from the environment and the RBC ultimately bursts.
RBC in isotonic IV solution with equal concentration of salt	The movement of water into and out of the cell is equal and the RBC is said to be in equilibrium with its environment.	There is no change in the size of the RBC.
RBC in a concentrated salt solution [hypertonic environment]	Water moves out of the cell into the surrounding saline solution.	The RBC shrivels as it loses water to the environment.

Jason used the *Osmobeaker* computer program (Meir, Stal, & Maruca, 2004) on Day 2 to build upon students' initial exploration of osmosis with dialysis tubing investigation on Day 1. The program engaged students with a scenario in which an emergency room patient, bleeding heavily from a serious wound, requires an intravenous infusion (IV infusion). Students were challenged to make predictions of changes in the red blood cell when the concentration of water within the IV solution was increased. Predictions were tested by running the program and noting changes. Jason noted three reasons for using the virtual investigation of osmosis: (1) animated representations of osmosis were observed at the molecular level, (2) the program allows students to manipulate variables and test predictions for each change, (3) calculating relative percentages of dissolved solids within each solution (within the virtual cell and the IV solution) challenged students to explain the direction of osmosis from greater to lesser concentrations mathematically. The virtual cell model offers an opportunity for students to observe osmosis at the molecular level and manipulate variables to immediately test

predictions; this would not be possible with the baggie, dialysis tubing or decalcified egg investigations.

Representations of Osmosis in Plant Organs

Teachers used potato slices, lettuce leaves, and the leaves and stems of Wisconsin Fast Plants as foci for investigations into osmosis.

Lettuce leaves. Kacy used lettuce leaves as a representation of a plant organ for the final osmosis investigation on Day 2. The lettuce leaves were placed in three different environments: distilled water, saline solution, and on a paper towel in the air. The goal of the investigation was to challenge students to think about osmosis as a ubiquitous process taking place in all living things. An overview of the lettuce leaf representation is shown in Table 35.

Table 35. *Lettuce leaves as representations for osmosis*

Representation: Lettuce Leaves		
External Environment	Direction of Net Water Movement	Evidence of Osmosis
Distilled water	Water enters lettuce leaf and leaf.	Lettuce leaf becomes rigid.
Saline Solution	Water leaves lettuce leaf.	Lettuce leaf becomes flaccid.
Paper Towel	Extreme water loss from lettuce leaf.	Lettuce leaf becomes flaccid, edges are dry.

Kacy’s intention was to support students as they constructed their knowledge of osmosis with a representation common to all students’ prior knowledge and experience.

Potato slices. Janis and Cathy used potato slices as representations for plant organs. The potato slices became rigid when placed in distilled water and flaccid when placed in a concentrated saline solution. First, Janis engaged students with an investigation into the direction of osmosis within *Elodea* leaf cells. Students observed changes at the cellular level when the leaves were exposed to distilled water and a

concentrated saline solution. Next, Janis engaged students with an investigation of osmosis in potato slices. She explained her goal was to engage students with an investigation into osmosis within plant organs; illustrating changes when multicellular structures undergo osmosis following placement in distilled water and a saline solution. Janis also challenged students to consider Wisconsin Fast Plants as representatives of osmosis within the context of observable changes within plant stems and leaves resulting from water loss. Janis noted that water uptake in the Fast Plants was an example of osmosis in complex plant organs (plant leaves and stems). Cathy sequenced her lessons to, first, investigate diffusion and osmosis in a dialysis tubing cell and, second, to investigate osmosis within potato slices as representations of plant organs. Students made and tested predictions by observing changes within the potato slices after exposure to each environment. An overview of the potato slice representation for plant tissues is shown in Table 36.

Table 36. *Potato slices as representations for osmosis.*

Representation: Potato slices		
External Environment	Direction of Net Water Movement	Evidence of Osmosis
Distilled water	Water enters potato slice.	Potato slice swells and becomes rigid.
Saline Solution	Water leaves potato slice.	Potato slice becomes flaccid.

Cathy and Janis explained students were familiar with potatoes and the commonality of students' experience served to engage students in constructing their knowledge of osmosis related to the diffusion of water from higher to lower concentrations within plant organs.

Interactive Lectures

All teachers used lectures as a format to provide students with information and to provide a format for students to share their observations, questions, and explanations. The teachers sequenced lecture and discussion to follow students' exploration of phenomena. In the lectures were teacher directed but included whole class discussions in which the teachers drew upon students' experiences, observations, and explanations.

Interactive lecture format. All six teachers engaged students with interactive lectures; teacher driven discussions during which PowerPoint presentations were used to provide computer graphics and animations of osmosis and diffusion. Emma, Janis, Jason, and Kacy used interactive lectures to engage students in constructing explanations for osmosis and diffusion following exploration of phenomena. The teachers explained their lesson sequence was designed to support the development of students' process skills including critical thinking, questioning, collaborating with peers, and evidence gathering. The lectures also served as a venue for teachers to present content to students including concepts related to membrane permeability, random molecular motion, and factors determining the direction of osmosis. However, Lana sequenced her lessons to began with a lecture focused on membrane permeability and terminology before investigating diffusion and osmosis and used the balloon demonstration and baggie investigation as validation for content presented during interactive lectures.

Instructional Sequence

Five of the six teachers used the following instructional sequence: (a) pre-assessed students' prior knowledge of diffusion and/or osmosis through predictions of demonstration or investigation outcomes, (b) engaged students with an exploration of the

phenomena, and (c) drew upon students' observations during interactive lectures to generate explanations for phenomena, and (d) challenged students to make and test predictions for new investigations. Teachers built upon students' knowledge of diffusion and osmosis from initial demonstrations and investigations to expand students' conceptual understanding to include random molecular motion as the driving force for the phenomena observed at the cellular level and within plant organs. Table 37 shows the sequence of concept introduction during the observed lessons.

Table 37. *Sequence of concept introduction during lesson*

Concept	Teachers					
	Emma	Janis	Cathy	Kay	Jason	Lana
Diffusion occurs in liquids and in gases	Lesson Sequence					
	1 food dye in water		1 food dye in water	1 food dye in water		1 cologne in balloon
Osmosis and diffusion occur at the cellular level	2 Egg	1 Elodea Leaf cells	2 Dialysis tubing	2 Baggie 3 Egg	1 Dialysis Tubing 2 Osmo- beaker	2 Baggie 3 Egg
Osmosis occurs within plant tissues, organs, and organisms		2 Potato slice 3 Fast Plants	3 Potato slice	4 Lettuce leaf		

Exploration of phenomena. Emma, Cathy, Kacy, and Lana initially engaged students with diffusion demonstrations (Emma, Cathy, and Kacy used demonstrations of diffusion in liquids and Lana used a demonstration of diffusion in gases) during which the diffusion of liquids and gases were observed. Students were challenged to make and test predictions of diffusion in each of the demonstrations.

Janis used an investigation of osmosis in cells within Elodea leaves to introduce students to osmosis, challenging students to make and test predictions of the direction of

osmosis. Jason initially engaged students with an investigation of osmosis and diffusion in artificial cells (dialysis tubing) students made and tested predictions for the direction of osmosis and diffusion of iodine and glucose. The teachers built upon students' initial observations of diffusion and osmosis to expand their understanding of random molecular motion and collisions as the driving force for diffusion and osmosis. To support students' understanding of random molecular motion, Cathy, Janis, Jason, and Kacy used computer animations to illustrate molecular motion driving osmosis. Emma and Lana used whiteboard diagrams with molecules of dissolved solid and water represented with contrasting symbols to illustrate molecular motion as the driving force for the phenomena.

Explanation. The teachers relied upon students' observations during demonstrations and/or investigations to generate explanations during interactive lectures. All six teachers used interactive lectures during which teachers: (a) asked students to share their observations with the class, (b) relied upon student ideas, observations, and experiences to generate explanations for the phenomena, and (c) used computer animations to provide engage students in explanations for diffusion and osmosis at the molecular level.

Elaboration. The sequence of demonstrations and investigations was designed to build upon students' initial understanding to construct a conceptual understanding of the phenomena as a result of random molecular motion and collisions. During the lessons, teachers challenged students to apply their understanding of diffusion and osmosis to new investigations or demonstrations for which the outcome was not known. All six teachers challenged students to predict the direction of osmosis and/or diffusion within the context

of new investigations or posed unique problems within existing investigations. Emma, Cathy, Lana, and Kacy initially challenged students to predict changes resulting from diffusion and progressed to challenging students to predict the direction of osmosis within cellular representatives. Janis and Jason initially challenged students to predict the direction of osmosis during investigations at the cellular level. Janis' lesson progressed to an investigation of osmosis at the level of plant organs (e.g., potato slices and Wisconsin Fast Plants). Jason challenged students to manipulate the concentration of dissolved solid within a virtual IV solution and predict the direction of osmosis following changes in the IV solution. Each of the teachers challenged students to build upon their understanding of osmosis and diffusion by predicting the direction of osmosis within new scenarios. An overview of the implicit 5E instructional sequence used by five of the six teachers during the research observation cycle is shown in Table 41.

Table 38. *Implicit 5E instructional sequence*

Teacher	Engage	Explore	Explain	Elaborate
Emma	Food dye and water diffusion demonstration	Decalcified egg investigation	Explanations developed from students' observations.	Students reverse eggs in distilled water and corn syrup
Cathy	Storyboard activity – Diffusion demonstration	Osmosis: <ul style="list-style-type: none"> • Dialysis tubing • Potato slices 	Students build upon knowledge of diffusion to formulate explanations of osmosis from observations.	Students predict and explain changes in potato slices placed in distilled water and saline.
Kacy	Food dye and water diffusion demonstration	Osmosis: <ul style="list-style-type: none"> • Baggie investigation • Decalcified egg investigation 	Students use test their predictions and use observations to explain the direction of osmosis.	Students predict and explain changes in lettuce leaves placed in distilled water, saline, and in the air
Jason	Review nature of plasma membrane	Osmosis: <ul style="list-style-type: none"> • Dialysis tubing investigation 	Explanations developed from students' observations.	Students make and test predictions of changes to virtual cell when water is added to virtual IV solution.
Janis	Observations of <i>Elodea</i> leaf cells	Osmosis: <ul style="list-style-type: none"> • Potato slice investigation 	Students' observations of osmosis in <i>Elodea</i> cells used to explain changes in potato slices.	Students will conduct an investigation of osmosis with dialysis tubing.

Practical applications

Practical applications were also important aspects of teachers' curricular knowledge and emphasized during instruction. All six teachers made connections between students' prior knowledge and experiences and osmosis and diffusion. Emma guided students to make connections between the nature of ocean water and fresh water and explain how drinking ocean water would result in dehydration. Jason, Kacy, and Janis made connections between osmosis and the importance of relative concentrations of dissolved solids within cellular contents and an IV solution. Cathy related her concern as a coach for student athletes' level of hydration, relating the important role of water in cell function and maintaining homeostasis.

Summary

Teachers sequenced lessons to initially engage students with demonstrations of diffusion or investigations into osmosis and diffusion at the cellular level and progressed to investigations of more complex plant structures (e.g., potato slices, lettuce leaves, and Fast Plants). Thus, a progression from simple to complex was observed among all teachers. Teachers explained the instructional sequence served to support student learning as they constructed their knowledge of diffusion and osmosis. Students were initially introduced to osmosis and/or diffusion at the cellular level. The teachers challenged students to build upon their understanding of osmosis at the cellular level to explain the changes observed in plant organs.

All teachers used representations of diffusion and osmosis to serve as foci for investigations and/or demonstrations. The teachers asked students to make and test predictions of changes resulting from diffusion and/or osmosis during demonstrations and

investigations. Five of the six teachers followed an implicit 5E instructional sequence. The teachers engaged students with explorations prior to formulating explanations and used students' experiences with the phenomena to develop explanations for their observations.

Teachers demonstrated knowledge of representations for diffusion and osmosis within non-living and living systems. The representations were selected because changes resulting from diffusion and/or osmosis were obvious for students. Several teachers implemented analogies to support students' learning by making connections between molecular motion and diffusion and osmosis. Representations served as a focus for demonstrations and/or investigations into diffusion and osmosis.

Assertion 3: The teachers identified three major areas of potential learning difficulties associated with students' conceptual understanding of diffusion and osmosis: (a) comprehension of vocabulary terms (hypertonic, hypotonic, isotonic, concentration gradient) and students ability to use vocabulary appropriately, (b) accurate prediction of the direction of net water movement during osmosis, and (c) difficulty visualizing and understanding osmosis and diffusion at the molecular level.

All six teachers identified two potential learning difficulties associated with students' conceptual understanding of osmosis and diffusion. First, all teachers noted that science has a unique language which can be confusing for students. Teachers noted students may not make connections between vocabulary terms (e.g., hypertonic, hypotonic, isotonic, concentration gradient, and permeable, semipermeable, and nonpermeable membranes) and observations of osmosis made during teacher demonstrations and laboratory investigations. Second, teachers believed students would have difficulty predicting the direction of osmosis during demonstrations and laboratory investigations. Third, teachers believed students would have difficulty visualizing osmosis and diffusion on a molecular level. Table 39, shown below, illustrates overview

of teacher knowledge of potential students' learning difficulties for diffusion and osmosis.

Table 39. *Overview of teacher knowledge of students' understanding of science*

Student Learning Difficulties	Teachers					
	Emma	Janis	Cathy	Kacy	Jason	Lana
Connecting vocabulary: hypertonic, hypotonic, isotonic, concentration gradient, and permeable, semipermeable, and nonpermeable membranes to the concept of osmosis.	X	X	X	X	X	X
Accurately predicting the direction of osmosis.	X	X	X	X	X	X
Visualizing osmosis and diffusion at the molecular level	X	X	X	X	X	X

Vocabulary as a Potential Learning Difficulty for Students

Students' understanding of osmosis relies upon comparing relative concentrations of dissolved solids within two solutions separated by a semipermeable membrane.

Vocabulary terms describing the relative concentration of dissolved solid include:

hypertonic, hypotonic, and isotonic. The terms semipermeable and concentration gradient describe the nature of cell membranes and the direction of osmosis based upon relative concentrations of water in two solutions. These terms are unique to the concept of osmosis and not commonly used with other concepts within tenth grade biology.

All six teachers expected students to have difficulty understanding vocabulary terms and definitions and noted that student difficulty with vocabulary could detract from conceptual understanding of osmosis. Kacy, Cathy, Emma, Janis, and Jason introduced the concept of osmosis prior to introducing vocabulary terms. Thus, vocabulary terms were introduced within the context of students' observations during demonstrations and/or investigations following students' exploration of phenomena.

Kacy was the only teacher who avoided any reference to the terms hypertonic, hypotonic, and isotonic and taught osmosis conceptually without referencing vocabulary terms. Basing her decision on prior teaching experience, Kacy noted vocabulary terms

would be difficult for students and ultimately distract students from achieving a conceptual understanding of osmosis. Janis introduced and established the concepts of membrane permeability and osmosis before introducing vocabulary terms. She noted her goal was to create a conceptual framework in which students could place new facts about osmosis including terminology. Emma, Cathy, and Jason introduced the terms hypertonic, hypotonic, isotonic, and concentration gradient during discussions of baggie, dialysis tubing, or decalcified egg investigations and taught vocabulary within the context of students' observations of osmosis. Lana introduced the terms during an initial lecture and emphasized the terms during discussions of students' observations.

Predicting the Direction of Osmosis

A major concern for the teachers was students' ability to accurately predict the direction of osmosis within a given scenario. Teachers explained tenth grade students have only a minimal understanding of chemistry and noted their limited knowledge of chemistry would make understanding abstract concepts related to the diffusion of water from greater to lesser concentrations difficult to accurately predict. All teachers used computer graphic or whiteboard diagrams of cells within beakers to support student understanding of the direction of osmosis. Assigning percentages of dissolved solid to the solutions within the cell and the beaker, the teachers challenged students to use the percentage of dissolved solid to calculate the percentage of water within each solution. Next, teachers challenged students to use this information to predict the direction of osmosis. Teachers used the relative percentages of dissolved solid and water within each solution to support students' understanding of a concentration gradient to predict the direction of osmosis.

Visualizing Random Molecular Motion as the Driving Force for Diffusion and Osmosis

Teachers noted tenth grade students lack a strong background in chemistry and were unlikely to perceive kinetic energy, random molecular motion, and molecular collisions as the driving force for osmosis and diffusion. All teachers believed students must be able to explain the driving force for both processes as kinetic energy, random molecular motion, and molecular collisions. To support students' understanding of diffusion and osmosis at the molecular level, Kacy, Janis, Cathy, and Jason relied upon computer animations of molecules to illustrate osmosis and diffusion in terms of the random motion and collision of molecules. Emma relied upon whiteboard diagrams of a cell placed in a solution within a beaker and used two different markings to represent molecules of water and dissolved solid within the beaker and cell solutions. She explained the marks represented molecules within each solution which were in constant and random motion, continually colliding with one another and gradually moving from greater to lesser concentrations. Emma's example was not a computer animation; however, she did address kinetic energy, random molecular motion, and molecular collisions as the driving force for osmosis. Lana also used a drawing of a cell within a beaker solution to represent osmosis and diffusion and used arrows to represent the direction of osmosis, relating the direction of water movement to the relative concentrations of water within each solution. Lana planned to engage students with an inquiry-based investigation of osmosis using decalcified chicken eggs following the research observation cycle. An explanation of osmosis at the molecular level may have been planned for that time.

Summary

Teachers identified students' understanding of vocabulary terms, students' ability to accurately predict the direction of osmosis, and visualizing random molecular motion and collisions as the driving force for osmosis as major student learning difficulties associated with the phenomena. All teachers noted the unique nature of the vocabulary and students' minimal knowledge of chemistry as underlying causes for students' learning difficulties. Teachers explained their concerns for students' learning difficulties were based upon past experiences with teaching osmosis and diffusion to tenth grade biology students and noted the use of animations and whiteboard diagrams illustrating osmosis were helpful in supporting students' conceptual understanding of the direction of osmosis. Teachers identified students' visualization of random molecular motion and collisions as the most abstract concept associated with osmosis and diffusion. Computer animations and whiteboard diagrams were used to support students' visualization of osmosis at the molecular level. Cathy and Janis used analogies of blindfolded students moving randomly and colliding within the classroom to make direct connections with students' prior knowledge and experience and to illustrate molecular motion as the driving force for diffusion and made.

Assertion 4: All teachers relied upon students' predictions to: (a) reveal students' prior knowledge, (b) assess students' current conceptual understanding, and (c) inform instructional decisions while teaching.

Formative Assessments

Pre-assessments are defined as tools or techniques used by the teachers in this study to reveal students' prior knowledge of diffusion and osmosis. Formative assessments are defined in this study as assessment tools used by teachers to reveal

students' current conceptual understanding of osmosis and diffusion. Formative assessments encompass multiple tools and include: teacher observations, classroom discussions, analysis of students' work, and making and testing predictions during investigations. Formative assessments were implemented by the teachers during investigations and instruction to reveal students' current conceptual understanding of the phenomena. An overview of pre-assessments and formative assessments used by teachers is shown in Table 40.

Table 40. *Pre-assessment and formative assessments for osmosis and diffusion*

		Teachers					
		Emma	Janis	Cathy	Kacy	Jason	Lana
P R E A S S E S S M E N T	<u>Making Predictions</u>						
	<u>Pre-assessment of Diffusion</u> Prior to teaching the concept of diffusion, students made predictions of changes resulting from diffusion.	X		X	X		X
M A K I N G P R E D I C T I O N S	<u>Pre-assessment of Osmosis</u> Prior to teaching the concept of osmosis, students made predictions of changes in living or artificial representations of cells.	X	X	X	X	X	X
	<u>Predicting Outcomes During Instruction</u> Teachers assessed students' conceptual knowledge through predictions of outcomes during instruction.	X	X	X	X	X	X
F O R M A T I V E A S S E S M E N T	<u>Testing Predictions</u> Students tested their predictions using observations and evidence gathered during investigations or demonstrations.	X	X	X	X	X	X
	<u>Explanation of Results</u> Students' observations and explanations of results from investigations.	X	X	X	X	X	X

Assessments are considered to be formative when student feedback informs the teachers' instruction to better meet students' learning needs and encourages students to self-evaluate the quality of their work. All six teachers used student predictions as a pre-assessment to reveal students' prior knowledge of diffusion and/or osmosis.

Pre-assessment of Diffusion

Emma, Kacy, Cathy, and Lana used student predictions as a pre-assessment to reveal students' prior knowledge of diffusion. Emma, Kacy, and Cathy challenged students to predict changes in a beaker of water when drops of food dye were added. Lana challenged students to predict the diffusion of molecules of cologne through the latex membrane of an inflated balloon. Emma, Kacy, and Cathy used predictions to focus students on the diffusion of liquids, whereas, Lana used predictions to focus students on the diffusion of gases through a latex balloon membrane (e.g., a semipermeable membrane). All four teachers used predictions to assess students' prior knowledge of diffusion prior to teaching the concept.

Pre-assessment of Osmosis

Janis used predictions of changes within cells of *Elodea* leaves to gain insight into students' prior knowledge of osmosis. Cathy and Jason challenged students to predict changes in dialysis tubing after placement in a solution of iodine and water prior to teaching osmosis. Kacy and Lana challenged students to predict changes in baggies containing a starch solution and placed in iodine and water. Before placing decalcified eggs in distilled water or corn syrup, Emma and Kacy challenged students to predict changes in the eggs. All six teachers noted they used student predictions to reveal students' prior knowledge of the phenomena.

Making and Testing Predictions during Instruction

All six teachers challenged students to predict the direction of osmosis and/or diffusion during investigations in which living (e.g., decalcified eggs) or artificial representations of cells (e.g., baggies or dialysis tubing) were placed in environments of greater or lesser concentrations of dissolved solids. Janis, Cathy, and Kacy challenged students to predict the direction of osmosis when plant organs (e.g., potato slices and lettuce leaves) were placed in solutions of varying concentrations. The teachers believed student predictions provided important insight into students' conceptual understanding during the lesson. All teachers implemented more than one investigation or demonstration, providing additional opportunities for students to predict the direction of osmosis and/or diffusion. Kacy used decalcified eggs placed in corn syrup as a demonstration of osmosis. Before showing the egg to students, Kacy challenged students to predict how the egg would change after placement in corn syrup. Jason repeatedly challenged students to predict changes following manipulations of the IV solution during the *Osmobeaker* (Meir, Stal, & Maruca, 2004) investigation. Emma challenged students to predict changes in decalcified eggs during the investigation before reversing the eggs within the distilled water and corn syrup environments. Lana planned to challenge students to predict changes in decalcified eggs during an inquiry-based investigation scheduled to take place during the following week. The teachers used students' predictions of changes in cells and plant organs to reveal students' conceptual understanding of osmosis and diffusion.

All six teachers challenged students to test their predictions by making careful observations of changes during demonstrations and investigations. The teachers noted

predictions focused students' thinking and stimulated students to self-assess their explanations of osmosis and diffusion. By challenging students to test their predictions, the teachers engaged students in assessing their own thinking and evaluating their ideas in light of the demonstration or investigation outcome. All teachers noted the importance of providing multiple opportunities for students to practice making and testing predictions and believed they were able to gain greater insight into student thinking by challenging students with multiple scenarios.

Student Explanations

All six teachers prompted discussions of osmosis by asking students to explain their observations. Students' explanations about the direction of osmosis and/or diffusion provided important insight into their understanding of how and why osmosis occurred. Jason, Kacy, Lana, and Cathy required students to provide written answers for analysis questions following investigations. Lana, Cathy, Jason, and Kacy read and responded to student explanations as formative assessments of students' conceptual understanding of the phenomenon. All four teachers noted students' written explanations provided important insights into their understanding. Jason required students to respond to analysis questions during the *Osmobeaker* (Meir, Stal, & Maruca, 2004) computer investigation; he collected student work and planned to provide written responses for the following lesson. Janis and Emma required students to record observations and measurements in data tables, evaluate predictions for accuracy, and write explanations for the outcome of investigations in laboratory notebooks which would be reviewed by the teacher to assess students' comprehension.

Teacher Observations

All six teachers interacted with students during the lessons to listen to students' comments during collaboration and to ask questions and evaluate student responses. The teachers explained by listening to students' comments during collaboration and questioning students about their ideas, they were able to better assess students' understanding during instruction.

Instructional Responses to Formative Assessments

All teachers relied upon formative assessments to inform their teaching. Teacher responses to formative assessments are organized into three major categories:

(1) animations to provide students with concrete examples of osmosis and diffusion at the molecular and cellular levels, (2) virtual or whiteboard diagrams of cells, and (3) teacher-directed analogies connecting diffusion and osmosis to common students' experiences.

Interactive computer programs used by the teachers included computer programs such as *Osmobeaker* (Meir et al. 2004) and interactive websites such as Molecular Logic (Concord Consortium, 2009). Table 41 illustrates teachers' response to pre-assessments and formative assessments during the observations.

Table 41. *Teacher response to pre-assessments and formative assessments*

Instructional Adjustments		Formative Assessments Inform Teaching					
		Emma	Janis	Cathy	Kacy	Jason	Lana
A N I M A T I O N S	<u>Animations</u>						
	Teacher uses MoLo animations showing random molecular motion and membrane permeability during osmosis and diffusion.		X	X	X	X	
	<u>Direction of Osmosis</u>						
	Teachers drew or used virtual diagrams of cells in beakers containing solutions of varying concentrations of dissolved solids. Students draw or described the orientation of arrows to indicate direction of osmosis into or out of the cell.	X whiteboard	X virtual	X virtual	X virtual	X virtual	X whiteboard
	<u>Analogies</u>						
	Teacher uses analogies designed to be common to students' prior experience and knowledge to explain membrane permeability, diffusion, and osmosis.	X	X	X	X	X	X

Computer animations. Teachers noted students' explanations did not include kinetic energy and the resulting random molecular motion. Janis, Cathy, Kacy, and Jason implemented computer animations from Molecular Logic (MoLo) (Concord Consortium, 2009) to support students' understanding of random molecular motion and collisions as the driving force for osmosis and diffusion. The teachers also included animations of cell membranes to emphasize the semipermeable nature of the membrane. By including animations at the molecular and cellular levels, Janis, Cathy, Kacy, and Jason addressed the gap in students' understanding of the role of molecular motion within the phenomena.

Diagrams. All teachers responded to students' confusion about the direction of osmosis by drawing diagrams or using virtual representations of cells. Because Lana and Emma did not use MoLo (Concord Consortium, 2009) animations, they relied upon whiteboard drawings of cells placed within beakers containing a solution in which the percentage of dissolved solid was identified. All six teachers noted that identifying percentages of dissolved solid enabled students to calculate the percentage of water in each solution, focusing students on water molecules moving from greater to lesser concentrations.

Analogies. When students appeared confused about the driving force for osmosis and diffusion, Cathy and Janis used an analogy of students as molecules. Students were described as blindfolded and moving randomly, colliding with one another within a crowded classroom. Cathy and Janis asked students to explain what would happen to the randomly moving students if a door were to be opened into the hallway. Cathy and Janis' goal was to stimulate students' thinking about diffusion and osmosis at the molecular level as driven by random molecular motion. To clarify the semipermeable nature of the dialysis tubing membrane for students, Jason used an analogy of a bouncer determining admission to a club. Jason used this analogy to help students understand osmosis at the molecular level. Smaller molecules (e.g., water, glucose, and iodine) were able to pass freely through the membrane but larger molecules (e.g., starch) remained within the tubing. In an effort to clarify students' comprehension of membrane structure, Janis and Lana used analogies emphasizing the fluid nature of the cell membrane. Janis described the membrane as consisting of floating plastic balls and rubber duckies within a bathtub; plastic balls represented the phospholipid molecules and the rubber duckies represented

proteins interspersed throughout the membrane. Lana described the fluid nature of the phospholipid molecules within the cell membrane as a race track in which phospholipid molecules were able to move freely, much like cars around a race track. Kacy used interactions between intravenous solutions (IV solutions) and body cells as an analogy for the interaction between demonstrations and investigations in which cells and plant organs were placed in solutions of varying concentrations. Kacy believed the analogy made the concept of osmosis relevant to students' lives.

Summary

In each case, teachers' inclusion of animations, diagrams, and analogies to redirect students' thinking was largely determined by the nature of feedback from their students. Student feedback took multiple forms including: making predictions, testing predictions, and explanations of observations during discussions, in notebooks, or in response to laboratory analysis questions. Responding to formative assessments, the teachers used representations to build connections between students' conceptual understanding of the phenomena and the concepts. All teachers implemented analogies, computer animations, and/or whiteboard diagrams to support students' construction of their conceptual understanding of the phenomena.

Assertion 5: Teachers relied upon state guidelines to identify learning goals related to diffusion and osmosis. They met or exceeded state guidelines by teaching random molecular motion as the driving force for the phenomena and included practical applications. The teachers made explicit connections across the horizontal curriculum.

General Biology Curriculum for Teaching Osmosis and Diffusion

The tenth grade biology curriculum is strongly influenced by Course Level Expectations (CLEs) and the End-of-Course exam (ECE) for tenth grade biology. The CLEs for tenth grade biology are organized to provide the framework and identify state

expectations for tenth grade biology students' learning. The End-of-Course (EOC) exams provide a uniform method for assessing students' knowledge of biology content of the specific learning targets identified by the CLEs. Student scores on the EOC exam provide teachers and administrators with a tool to evaluate the success of curricular programs, assess student learning, and compare student progress with districts throughout the state and are used to evaluate school and district success. Hence, both the CLEs and the EOC exams inform the development of general biology curriculum. The CLE which guided this study was taken from Strand 3 (see Chapter One) and identified learning requirements for osmosis and diffusion.

All six teachers met and exceeded the goals for teaching the concepts of diffusion and osmosis within curricular guidelines established within the tenth grade biology curriculum. All teachers used living or artificial representations of cells to illustrate the semipermeable nature of the cell membrane as well as diffusion and osmosis at the cellular level. The teachers went beyond curricular requirements by identifying random molecular motion and molecular collisions as the driving force for osmosis at the molecular level. Using computer animations or whiteboard diagrams to represent diffusion and/or osmosis, teachers modeled random molecular motion, concentration gradient, and relative tonicity as driving forces for osmosis and diffusion.

Horizontal Curricular Connections

All six teachers exceeded standards identified within the CLEs by making horizontal connections within the tenth grade biology curriculum to identify random molecular motion and collisions as the driving force for the phenomena, reminding

students of the semipermeable nature of the cell membrane as a factor in osmosis, and by including practical applications of osmosis and diffusion in students' lives.

All teachers addressed Strand 2 (kinetic energy and random molecular motion as important aspects of the tenth grade biology curriculum) earlier during the fall semester; the teachers referenced the concept of random molecular motion as the driving force for osmosis and diffusion during the observation cycle.

Summary

The teachers met and exceeded state guidelines by emphasizing random molecular motion and collisions as the driving force for both diffusion and osmosis. The teachers supported students' construction of their knowledge of the phenomena with computer animations of molecular motion across semipermeable cell membranes during osmosis. All of the teachers emphasized practical applications for osmosis by making connections between the direction of osmosis and concentrations of dissolved solid in IV solutions which are isotonic to human blood. The teachers also made connections between diffusion and osmosis and other concepts addressed in general biology. The teachers explained students' understanding of diffusion and osmosis are critical for understanding other life processes including: photosynthesis and cellular respiration. Hence, students were able to apply their understanding of osmosis at the molecular level to observations of osmosis to virtual cells and plant organs.

Assertion 6: Teachers drew on their highly integrated PCK to create learning opportunities designed to scaffold students' learning of osmosis and diffusion, progressing from concrete to abstract representations.

The components of the teachers' PCK do not function as separate entities, instead teachers integrate the components of their PCK to design and execute lessons which are

reflective of their goals and purposes for teaching biology. The lessons designed and carried out by all six teachers were strongly influenced by three factors. First, the teacher's orientation for science teaching identified the goals and purposes of the lesson as well as the perception of teacher and student roles, and, by doing so, informed every aspect of the lesson. Second, the highly integrated components of teacher knowledge (e.g., knowledge of representations, instructional strategies, students as learners, assessment, and curriculum) informed the choice of representations, demonstrations, and investigations for the lesson. The instructional sequence of the lesson was reflective of the teachers' perception of students as learners as well as their knowledge of representations and instruction strategies for osmosis and diffusion. For instance, Lana elected to engage students in a lecture prior to conducting an investigation into osmosis and diffusion. She believed students would have difficulty conducting an investigation as an exploration of the phenomena. Hence, the sequence of instruction was influenced by the perception of students as learners held by the teacher and beliefs about what the students would be able to do and understand within the context of the lesson. Third, teacher planning was influenced by past experiences with teaching osmosis and diffusion to tenth grade biology students. These three factors influenced the integration of the components of PCK resulting in a reform-based or traditional instructional sequence, the selection of representations, instructional strategies, assessments, and curricular resources to support students' conceptual understanding of the concepts.

During teaching, the teachers applied previously designed lesson plans to the realities within the context of the classroom. Figure 27 illustrates the integration of the components of PCK during planning and teaching.

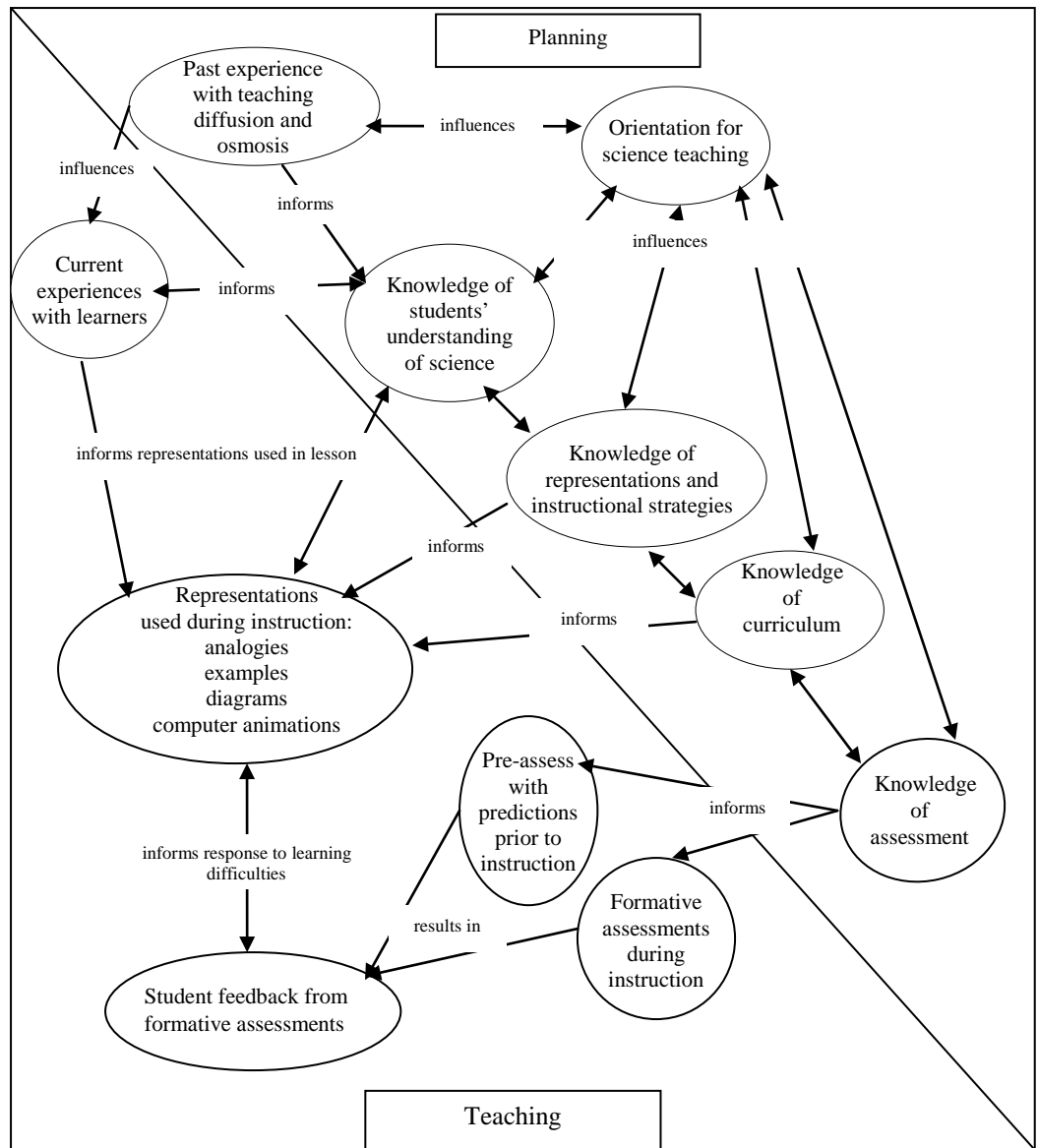


Figure 27: *Integration of teacher knowledge for teaching osmosis and diffusion*

All teachers drew upon their components of teacher knowledge to inform their practice. They used pre-planned representations to served as foci for demonstrations and investigations into diffusion and osmosis at the cellular or plan organ levels. All teachers created lesson plans to guide their teaching during both days of the observation. However, each teacher responded to student difficulties within the context of the lesson and the current realities of the classroom. The teachers implemented pre-assessments and

formative assessments to reveal students' prior knowledge or conceptual understanding of the phenomena. The knowledge gained informed instructional decisions made during the lesson.

Lesson Progression from Concrete to Abstract Representations

The teachers were aware students often have difficulty understanding the fundamental concepts of diffusion and osmosis. To address their concerns for students' learning, all teachers designed lessons to initially engage students with demonstrations of diffusion or laboratory investigations of osmosis and diffusion at the cellular level. Demonstration and investigation outcomes resulted in obvious evidence of diffusion and/or osmosis, providing concrete representations of the phenomena. To encourage students to build upon their initial understanding of the phenomena, teachers engaged students with investigations focused on increasingly complex representations of semipermeable membranes, diffusion, and osmosis. Kacy and Lana progressed from an initial diffusion demonstration to a baggie investigation in which students investigated diffusion and osmosis between a baggie solution containing starch placed in an environment of distilled water and iodine. Changes in baggie volume and color served as evidence for the direction of osmosis and diffusion of iodine into the starch solution within the baggie. Emma followed an initial diffusion demonstration with an investigation into osmosis focused on changes in decalcified eggs placed in corn syrup or water. During the investigation, Emma challenged students to reverse the eggs and predict changes when placed in the opposite environment. Following an initial dialysis tubing investigation, Jason challenged students to predict the direction of osmosis in a virtual cell within an environment in which students manipulated the concentration of

dissolved solid. Janis, Cathy, and Kacy progressed to investigations into osmosis within plant tissues (e.g., potato slices and lettuce leaves).

The sequence of instruction was informed by teachers' experience with teaching diffusion and osmosis as well as their knowledge of students as learners, knowledge of curricular resources, and representations and instructional strategies. The integration of PCK components with prior experience with teaching osmosis and diffusion resulted in lessons which engaged students with clear, concrete representations and moved to more abstract representations in which the effect of osmosis was not as easily observed.

Student predictions as a formative assessment

A major concern for all teachers was students' ability to accurately predict the direction of osmosis during investigations at the cellular and plant organ level. All teachers utilized student predictions of demonstration or investigation outcomes as a pre-assessment of students' understanding of the phenomena prior to instruction and to assess students' conceptual understanding of the phenomena during instruction.

Students used their observations during demonstrations and investigations to test predictions and support explanations for the direction of osmosis. Students' rationale for predictions and explanations of investigation outcomes during exploration of phenomena and explanation-building served as formative assessments. Knowledge of students' conceptual understanding revealed through pre-assessments and formative assessments often resulted in corrective action taken by teachers to adjust their instruction including the implementation of computer animations, analogies, and diagrams to help students visualize the movement of water from areas of greater to lesser concentration.

Summary

The PCK held by these experienced teachers has been highly integrated through years of teaching experience and this integration of the components of teacher PCK and subject matter knowledge informed all aspects of their teaching. The orientation to science teaching served as a lens through which the teachers identified goals and purposes, student and teacher roles were viewed, informing all aspects of the lessons. Teachers relied upon their knowledge of students as science learners to predict potential difficulties and identify the most effective representations coupled with formative assessments to reveal students' conceptual understanding. Teacher planning and teaching was reflective of past experience with teaching the phenomena. Hence, the teachers' knowledge was informed by their experiences creating topic-specific knowledge for teaching diffusion and osmosis. Over time, experience with teaching, learning, and learners shapes teacher PCK to create knowledge for teaching which has been thoroughly integrated and reflective of their teaching practice. Thus, experienced teachers perceive their students as science learners and are able to relate potential learning difficulties to the nature of representations, instructional strategies, and formative assessments necessary to make concepts understandable for students and use feedback on assessments to adjust their teaching. Effective teaching is a complex interaction between the teacher and the students. Effective learning occurs only when teacher knowledge is highly integrated. This integrated knowledge supports effective lesson design which addresses the learning needs of the students with meaningful and relevant learning opportunities with students' comprehension monitored through formative assessments. Hence, the integrated nature of

teacher PCK is characteristic of effective and experienced teachers and also necessary for student learning.

CHAPTER SIX: CONCLUSION AND IMPLICATIONS

The purpose of this study was to investigate the nature of pedagogical content knowledge held by experienced biology teachers and how the teachers draw upon this knowledge when teaching lessons on diffusion and osmosis to tenth grade general biology students.

Research Questions and Sub-questions

Six research sub-questions guided the analysis, interpretation, and writing of this study. The research sub-questions were:

1. What are the nature and sources of the experienced biology teachers' orientations to science teaching?
2. What is the nature of experienced biology teachers' knowledge of representations and instructional strategies and how does this knowledge inform their teaching practice?
3. What is the nature of experienced biology teachers' knowledge of students' understanding of science and how does this knowledge of science learners inform their teaching practice?
4. What is the nature of experienced biology teachers' knowledge of formative assessment strategies and how does this knowledge inform their teaching practice?
5. What is the nature of experienced biology teachers' knowledge of biology curriculum and how does this knowledge inform their teaching practice?
6. In what ways do experienced teachers integrate the topic-specific components of their pedagogical content knowledge when teaching osmosis and diffusion?

This chapter includes the following sections: (a) a summary of research findings; (b) a comparison of the findings in relation to the education literature discussed in Chapter Two and a discussion of how this study contributes to an understanding of the topic-specific PCK of experienced teachers; (c) implications of this research for the preparation of prospective science teachers and professional development for experienced teachers, as well as for research and policy; and (d) conclusions.

Summary of Research Findings

Question One: The Nature and Sources of Teachers' Orientation to Teaching Biology

The focus of the first research question is to identify the nature and sources of orientations for teaching biology held by the participants. I assert that five of the six participants held a constructivist orientation to teaching biology, while the sixth participant held a knowledge-transmission orientation. The common theme for the constructivist teachers was the implementation of an implicit 5E (Bybee, 1997) instructional sequence. The teachers had students explore the phenomenon and drew upon students' observations to construct explanations. They challenged students to extend their conceptual understanding by having them apply their knowledge to new scenarios. The teacher with the knowledge-transmission orientation engaged students with a teacher-directed lecture during which explanations of phenomena were provided prior to a validation laboratory activity. During interviews, this teacher noted her ideal image of teaching biology was to implement the 5E (Bybee, 1997) instructional model. However, her beliefs about learners and learning acted as a constraint to the implementation of the 5E (Bybee, 1997) model resulting in an knowledge-transmission instructional approach for teaching biology (see Assertion 1 in Chapter Five).

Question Two: Experienced Biology Teachers' Knowledge of Representations and Instructional Strategies for Teaching Diffusion and Osmosis

The second question addresses the nature of experienced biology teachers' knowledge of representations and instructional strategies for teaching diffusion and osmosis. There were common themes noted among the representations used by the teachers in their lessons. First, four of the teachers initially engaged students with observations of diffusion before progressing to investigations of osmosis. For example, one of the teachers challenged students to develop a series of drawings illustrating the process of diffusion. Second, all six teachers used artificial or living representations of cells to illustrate diffusion and osmosis. Third, progressing from living or artificial cell models to living plant tissues, all of the teachers challenged students with making and testing predictions of the outcome of demonstrations and laboratory investigations of diffusion and osmosis. Fourth, all six teachers used either virtual animations or whiteboard representations of osmosis and diffusion to emphasize random molecular motion and a concentration gradient as the driving force for diffusion and osmosis. In addition, all six teachers noted the importance of the instructional sequence within their lessons; five of the six teachers used an implicit 5E (Bybee, 1997) instructional model and one teacher relied upon a knowledge-transmission approach to teaching (e.g., lecture followed by a confirmation laboratory investigation).

Question Three: Knowledge of Students as Learners

The third question addresses teachers' knowledge of students as learners, students' prior knowledge, requirements for students' learning, and potential learning difficulties associated with diffusion and osmosis. The teachers held strong beliefs about

students as learners. First, all six teachers perceived vocabulary to be a potential learning difficulty for students. Second, the teachers used students' predictions of outcomes of demonstrations and investigations to gain insight into students' prior knowledge of diffusion and osmosis. Third, five of the six teachers believed students learned most effectively as active participants in learning and engaged students with laboratory investigations of diffusion and osmosis. The sixth teacher believed students were not prepared to conduct investigations and initially engaged students in a teacher-directed lecture with a focus on the transmission of knowledge about diffusion and osmosis. The teachers' beliefs about students as learners were very powerful and informed their teaching.

Question Four: Knowledge and Utilization of Formative Assessment

Question four addresses the knowledge of formative assessment strategies held by the teachers and the manner in which the teachers utilized students' feedback on formative assessments to guide their teaching. Several themes emerged from the data. First, all six teachers utilized formative assessments during teaching. The teachers challenged students to predict the outcomes of demonstrations and investigations as a means of revealing students' prior knowledge before teaching and to assess students' conceptual understanding of phenomena during teaching. Second, the teachers interacted with students, listening to comments, explanations, and questions while students collaborated on making and testing predictions. All six teachers described the nature of students' comments, questions, and conversations as good indicators of students' prior knowledge and/or conceptual understanding of phenomena. Third, teachers utilized students' responses to analysis questions associated with laboratory investigations to

gauge students' conceptual understanding. The teachers understood the importance of revealing students' prior knowledge and conceptual understanding. Relying upon their experience with teaching biology, the teachers implemented several different formative assessments to reveal students' thinking, inform instructional decisions, and stimulate students' reflection upon their own work.

Question Five: Teacher Organization and Sequence of the Biology Curriculum

Question five addresses teacher organization and sequence of the biology curriculum to support students' learning. The topics covered in the tenth grade biology curriculum are dictated by state and school district guidelines. Even though participants in this study taught at six different high schools ranging from small rural schools to large suburban schools, the organization and content of the biology curricula were very similar. All six teachers related the importance of diffusion and osmosis to both the vertical and horizontal curricula. The teachers made connections to concepts taught earlier in students' educational experience emphasizing the importance of concepts taught within the vertical curriculum. The teachers identified cell biology, photosynthesis, cellular respiration, and homeostasis as concepts within the horizontal curriculum which build upon students' understanding of a semipermeable cell membrane as well as diffusion and osmosis. The teachers perceived biology as a way of explaining life and the interconnected nature of life processes. Hence, teachers made connections between diffusion and osmosis, the semipermeable nature of cell membranes, and the maintenance of homeostasis within cells to stimulate an understanding of the ubiquitous nature of diffusion and osmosis among all living organisms.

Question Six: The Integration of PCK Components

All six teachers integrated the components of their pedagogical content knowledge (e.g., knowledge of representations and instructional strategies, knowledge of students' understanding of science, knowledge of assessment, knowledge of curriculum) to create learning opportunities for their students. Teachers relied upon their knowledge of subject matter, representations, instructional strategies, assessment, and curriculum to create opportunities which engaged students in making and testing predictions as well as supporting claims and conclusions with evidence.

Discussion

In this section, I revisit the literature review in Chapter Two, the case profiles in Chapter Four, and the in-case and cross-case analysis of findings in Chapter Five. My purpose in this chapter is to compare the findings of this study to the existing literature base and to highlight how this study contributes to the literature. The literature review revealed a significant gap in the literature examining the practice and pedagogical content knowledge held by experienced teachers for teaching specific topics in science. In the following, I discuss the similarities and differences between the reviewed literature and my research findings. This chapter is organized in a sequence similar to that of the assertions presented in Chapter 5.

Orientation to Science Teaching

The orientation to teaching science acts as a lens through which the other components of pedagogical content knowledge (e.g., knowledge of representations, instructional strategies, students' understanding of science, assessment, and curriculum) are interpreted, integrated, and enacted (Friedrichsen, & Dana, 2003, 2005; Grossman, 1990; Magnusson et al. 1999). When designing the study, I initially drew upon the

orientations to science teaching proposed by Magnusson et al. (1999). Predicated upon Grossman's (1990) conceptions of science teaching, Magnusson et al. (1999) reviewed science education literature and identified nine orientations to science teaching including: (1) process, (2) academic rigor, (3) didactic, (4) conceptual change, (5) activity-driven, (6) discovery, (7) project-based, (8) inquiry, and (9) guided inquiry. However, when analyzing the data from this study, I found teacher orientations to be a complex construct, not sufficiently explained by the nine orientations defined and described by Magnusson et al. (1999). To gain a better understanding of the orientations to science teaching held by participants in this study, I reviewed education research literature in both science and mathematics. Within science education literature I drew upon the work of Brown (2008), Brown, Abell, and Friedrichsen (2008), Friedrichsen (2002), and Friedrichsen and Dana (2003, 2005) to understand the complex nature of teacher orientations and better represent the complexity of the orientations to science teaching held by participants. Friedrichsen and Dana (2005) described teachers' orientations as complex and driven by "aspects of two or three orientations described in the literature" (p. 221). Friedrichsen (2002) found teacher orientations to be strongly influenced by teacher beliefs about students' attitudes toward science and readiness for college. Brown (2008) and Brown et al. (2008) expanded teacher orientations to include five dimensions: (1) goals and purposes for teaching science, (2) perception of teacher role, (3) perception of student role, (4) ideal images of teaching science, and (5) perception of science as a discipline. Hence, I drew upon the work of Brown (2008) and Brown et al. (2008) to gain important insight into the perceptions held by the teachers about their role as teachers and the role of their students in learning.

I drew upon mathematics education literature to expand my understanding of the influence of teacher orientation on teacher actions. Marks (1990), Ma (1999), and Ball and Bass (2000) stressed the importance of teachers' beliefs about students' roles as learners of mathematics and noted teachers' beliefs informed teacher actions in the classroom. By relying upon a broad base of science and mathematics literature I was able to gain a deeper understanding of orientations to teaching, sources of teacher orientations, and how teacher orientations inform teacher actions. Both the mathematics and science education literatures emphasize the goals and purposes for teaching content as well as the perceptions of students as learners as important sources of teachers' orientation to teaching mathematics or science.

Building upon the work of Brown (2008) and Brown et al. (2008), I examined teachers' orientations to teaching science through five dimensions to enhance my understanding of the nature of the orientations to science teaching held by participants and to explain the sources of teacher orientation through the lens of their goals and purposes for teaching science, their beliefs about the roles of teachers and students in learning, and their perception of science as a discipline.

I assert five biology teachers in this study held constructivist beliefs about teaching and learning which supported their perception of effective science learning as students constructing their knowledge. Jason, Janis, Cathy, Emma, and Kay believed students learn most effectively as active participants in learning. The teachers engaged students in conducting investigations and drawing upon their experiences and observations during investigations of phenomena to construct their knowledge of biology. The teachers initially engaged students with explorations of diffusion and osmosis,

encouraging the construction of a conceptual framework prior to generating explanations supported with their observations. Students drew on their conceptual framework to make sense of new ideas about the nature of diffusion and osmosis. The teachers emphasized their goal of supporting students' understanding of the processes and skills involved in biology by engaging students with explorations of phenomena, making and testing predictions, making observations, and supporting explanations with evidence. These findings are congruent with findings of Borko and Putnam (1996); the researchers investigated teachers with a constructive orientation for teaching science. The findings indicate an effective constructivist approach to teaching science relies heavily upon teachers supporting students' learning by engaging students with scientific question and emphasizing the importance of evidence in developing and evaluating explanations and finding answers to scientifically oriented questions.

Lana's orientation to science teaching differed markedly from the orientations held by other study participants. Lana identified laying the groundwork for students' understanding of biological concepts as one of her purposes for teaching biology. She believed her students knew little of biology and, as a result, were not prepared to conduct and learn from explorations of phenomena. Hence, Lana initially engaged students with a teacher-directed lecture to explain phenomena and define vocabulary prior to introducing phenomena through an exploration. Lana identified teaching biology through the 5E (Bybee, 1997) instructional model as one of her goals for teaching biology, however, this goal was in conflict with the beliefs she held about how students learn best. Brown (2008) believed by investigating teacher orientations through five dimensions, he could

more accurately explain teacher actions. I found that the dimensions of teacher orientation were critical for understanding and explaining Lana's actions during teaching.

The participants' orientations to science teaching were driven by their beliefs about the roles of teachers and students in learning and how students learn most effectively. This finding is congruent with findings by Lotter, Harwood, and Bonner (2007), Deemer (2004), and Volkmann and Zgagacz (2004) who found teachers' core beliefs about learning and teaching informed the implementation of inquiry-based instructional strategies. Thus, the orientation to science teaching held by the teacher informs instructional decisions made during planning and teaching. However, few studies were found which investigate the orientation to science teaching held by experienced teachers, indicating an important gap in the science education research literature. This study investigates the nature and source(s) of teachers' orientation to teaching held by experienced biology teachers and addresses the gap in the literature.

Teacher Knowledge of Representations and Instructional Strategies

All six teachers implemented representations to illustrate diffusion and osmosis. Representations designed to support students' conceptual understanding of phenomena at the molecular-level, the cellular-level, and the plant organ level and served as the foci for demonstrations and laboratory investigations. For example, Cathy and Janis relied upon an analogy of blindfolded students moving randomly and colliding with one another to identify random molecular motion as the driving force for diffusion and osmosis. Mastrilli (1997) would describe this as a simple, descriptive analogy. The teachers used the analogy to support students' learning by making connections between the abstract concept of random molecular motion and the concrete example of random motion

experienced by blindfolded students as they moved from areas of greater to lesser concentrations.

All six of the teachers implemented models to support students' conceptual understanding of the particulate nature of matter (e.g., random molecular motion), the nature of semipermeable membranes, the direction of osmosis and diffusion in living and artificial representations of cells, as well as osmosis in plant organs. These models served as foci for laboratory investigations used by all of the teachers. All six teachers challenged students to make and test predictions of the direction of diffusion and/or osmosis when the cell or plant organ models were placed in solutions of varying concentrations of dissolved solids. Four of the six teachers expanded their use of models to include computer animations as interactive models. Again, the teachers challenged students to predict the direction or rate of osmosis when changes were made to the virtual model. The computer animations served as a basis for whole class discussions of factors which drive and influence the direction or rate of diffusion and osmosis. Emma and Lana did not implement computer animations; instead, the teachers relied upon whiteboard diagrams of two solutions separated by a semipermeable membrane. The teachers manipulated the whiteboard models, changing percentages of dissolved solid within the solution in which the cell was shown. Next, students predicted and explained resulting changes in the direction of osmosis within the whiteboard model. The literature indicates the majority teachers perceive models as concrete representations of abstract concepts rather than as learning tools manipulated by students (Justi & Gilbert, 2002a, 2002b; Van Der Valk et al. 2007; Van Driel and Verloop, 1999, 2002). However, the findings of this study indicate these experienced biology teachers recognized and used models as learning

tools and consistently challenged students to make and test predictions of the direction of osmosis.

Van Driel et al. (1998) described two key elements of PCK: (1) an integration of subject matter knowledge with knowledge of instructional strategies and representations and (2) knowledge of students' learning difficulties with the content. The findings of this study support the findings of Van Driel et al. (1998) in that the teachers' use of analogies and models indicates an integration of their knowledge of subject matter with their knowledge of representations, instructional strategies, and students as science learners. This study investigated the PCK of experienced teachers for teaching diffusion and osmosis, a specific topic in biology. Teacher observations and interviews indicated strong subject-matter knowledge as well as knowledge of representations and instructional strategies. This study adds to the literature by making experienced teachers' use of representations as learning tools explicit. Much of the science education literature is focused on the practice of prospective and novice teachers, identifying their use of representations and instructional strategies. However, this study makes the practice of experienced teachers using models as learning tools in their teaching practice explicit. Such explicit descriptions of experienced teachers teaching specific topics are absent from science education literature.

Five of the six participants used an implicit 5E instructional sequence (Bybee, 1997) to engage students in explorations of phenomena before drawing upon students' observations during interactive lectures to construct explanations. The instructional strategies implemented by the teachers supported students' construction of knowledge of diffusion and osmosis. Findings of this study indicate the majority of teachers organized

their instruction in a 5E (Bybee, 1997) instructional sequence. Janis, Emma, and Cathy indicated they received formal training with the 5E (Bybee, 1997) model through Masters' programs and professional development and chose to use this model in their teaching. Jason and Kacy had not received formal training with the instructional model but had intuitively structured their instruction to reflect the 5E sequence.

Prospective science teachers often complain classroom teachers do not implement inquiry into their teaching (Crawford, 2007). This study reports use of an implicit 5E (Bybee, 1997) instructional sequence by the majority of participants. The stages of the 5E (Bybee, 1997) model were not explicitly identified by participants nor did they use the terminology when reflecting upon their lessons. This study contributes an explicit description of lessons in which an implicit 5E (Bybee, 1997) instructional sequence was implemented by experienced biology teachers.

Teacher Knowledge of Students' Understanding of Science

Wallace and Kang (2004), Cohen and Yarden (2009), and Cronin-Jones (1991) investigated teacher beliefs about how students learn science. The researchers found teachers' beliefs about students' limitations, maturity, or learning difficulties with topics in science influenced the nature of instruction, the implementation of curriculum, and informed teacher actions in the classroom. In a study of middle school science teachers, Cronin-Jones (1991) found teachers' beliefs about science learners were important factors in determining teacher actions. The findings of this study indicate teachers' beliefs about how students learn science led them to engage students with an exploration of concepts prior to an explanation. The teachers believed students would learn effectively as active participants, exploring concepts, and developing explanations supported with their

observations; however, Lana believed her students were not ready to conduct explorations prior to explanations. The findings of this study indicate Lana's beliefs about students as science learners acted as a constraint for engaging students to initially explore the phenomenon. Hence, the findings of this study confirm teacher beliefs about student learning are important factors and inform teacher actions and the nature of their instruction.

All six teachers believed prior knowledge to be an important factor in students' learning. The teachers revealed students' thinking and prior knowledge by challenging students to make and test predictions. This finding is supported by studies investigating the influence of prior knowledge upon student learning conducted by Athanassios and Komis (2003) and Jones et al. (1999). Both studies investigated teacher exploration of students' understanding of scientific concepts and found students' conceptions resulted from their experiences and were often incompatible with scientific theories. Hence, findings from both studies emphasized the importance of revealing students' prior knowledge to address students' misconceptions prior to instruction. Few studies examined teacher beliefs about students' understanding of science for specific topics. This study is important for two reasons. First, it addresses teachers' understanding of science learners. All six of the participants demonstrated strong knowledge of students and the importance of students' prior knowledge in learning science. Second, the participants in this study demonstrated the use of students' predictions as a means of gaining insight into students' thinking. Initially, the teachers used the nature of students' predictions to reveal students' prior knowledge. During instruction, the teachers used predictions to assess students' conceptual understanding of phenomena.

All of the teachers in this study identified potential learning difficulties associated with diffusion and osmosis including: (a) vocabulary terms, (b) random molecular motion and collisions as the driving force for both phenomena, and (c) direction of osmosis relative to concentrations of dissolved solids between two solutions separated by a semipermeable membrane. Driver et al. (2003) identify the ability to predict potential student learning difficulties as a critical aspect of teacher PCK. Findings of earlier studies identified similar misconceptions among high school and collegiate students studying diffusion and osmosis (Christianson & Fisher, 1999; Odom & Barrow, 1995; Odom & Barrow, 2007; Odom & Kelly, 2001; Tekkaya, 2003; and Zuckerman, 1993). However, these studies focused on students' conceptual understanding of diffusion and osmosis and did not investigate the PCK held by the teachers for teaching the phenomena. This study makes explicit the nature of experienced teachers' PCK for learners. Hence, during observations the teachers demonstrated a strong awareness of potential student misconceptions and used students' predictions to reveal prior knowledge. Students' predictions provided important insights into students' prior knowledge and conceptual understanding. Teachers also held specific beliefs about potential learning difficulties students would have with the phenomena and used this knowledge to inform their instruction and support students learning. First, the teachers believed students' understanding of the unique vocabulary terms associated with diffusion and osmosis would constrain learning. Five of the six teachers engaged students with explorations of the concepts prior to introducing vocabulary terms, introducing concepts first. Second, the teachers believed students would have difficulty predicting the direction of osmosis. All six teachers engaged students with investigations of osmosis in cells and/or plant

organs and challenged students to make and test predictions of the direction of osmosis. Third, the teachers believed students would not identify random molecular motion as the driving force for diffusion and osmosis. The teachers used interactive computer animations or whiteboard diagrams to represent molecular movement during diffusion and osmosis. This study makes the PCK of experienced teachers explicit and shows how experienced biology teachers addressed students' misconceptions and learning difficulties. Making the knowledge and practice of experienced teachers explicit for teaching a specific topic in science is important because it provides examples of topic-specific case knowledge which can be used in teacher preparation and professional development programs (Shulman, 1988).

Teacher Knowledge of Assessment in Science

All six participants held strong beliefs about the nature and importance of assessment in terms of facilitating students' learning. The teachers used similar forms of formative assessment to pre-assess students' prior knowledge and reveal misconceptions including: (a) predictions of outcomes for demonstrations and laboratory investigations, (b) interactions between students during collaborative in-class work, (c) questions posed by students, (d) student responses to questions posed by the teacher, (e) written responses to analysis questions associated with demonstrations and investigation, and (f) students' facial expressions and body language. These formative assessments were used in various combinations by all of the teachers to gain insight into students' conceptual understanding of the phenomena. Earlier studies reported two categories of formative assessments implemented by New Zealand middle school and high school teachers including: (a) planned formative assessments and (b) interactive or informal formative

assessments (Cowie & Bell, 1999; Bell & Cowie, 2001). Participants in this study used students' predictions as informal formative assessments prior to investigations to gain insight into students' prior knowledge and identify misconceptions. During instruction, students' predictions revealed students' conceptual understanding of phenomena. Hence, the nature of students' predictions informed teacher actions prior to and during instruction. The findings of this study made explicit experienced teachers' use of informal formative assessments. Participants in this study demonstrated a strong understanding of potential learning difficulties and students' misconceptions associated with diffusion and osmosis. Hence, this study reports topic-specific, informal formative assessments used by experienced high school biology teachers.

Liew and Treagust (1998) and Ruiz-Primo and Furtak (2006) support the findings of this study in terms of the tacit application of informal formative assessments to reveal students' conceptual understanding as pre-assessments and informal formative assessments embedded in instruction. All six teachers implemented formative assessments as a tacit process during teaching and utilized students' feedback to guide next steps during the lesson.

Morrison and Lederman (2003) reported few teachers used probing questions to reveal students' prior knowledge before teaching. The teachers in this study were aware of potential misconceptions and utilized students' predictions as a means of revealing prior knowledge before teaching. Unlike participants in the Morrison and Lederman (2003) study, Kacy and Emma, participants with the least teaching experience (seven and eight years of teaching experience respectively) noted the importance of revealing

students' prior knowledge. These teachers used students' predictions and probing questions to reveal students' prior knowledge and conceptual understanding of concepts.

The findings of this study contribute to the literature by making teachers' knowledge of students as science learners and the use of informal formative assessments explicit. During observations and interviews, the teachers revealed the unique nature of students' difficulties associated with diffusion and osmosis and explained how this knowledge informed their instruction. The teachers identified the informal formative assessments embedded within their instruction and noted how these assessments revealed students' thinking and informed their instruction. The teachers used students' predictions throughout their lessons; first to reveal students' prior knowledge, and during instruction to assess students' conceptual understanding. The nature of students' predictions revealed their level of comprehension and provided insight into students' thinking and informed the next steps in the lesson. Experienced teachers' use of formative assessments needs to be made explicit to provide insight for prospective and novice teachers.

Teacher Knowledge of Science Curriculum

All six teachers noted the content of tenth grade biology is largely determined by state guidelines and the district curriculum. Avery and Carlsen (2001) investigated the implementation of curriculum by teachers and noted, as curriculum users, teachers adapted the curriculum to address curricular mandates and include instructional models to support students' learning. My study confirmed the findings of Avery and Carlsen (2001). My study contributes to the literature by showing the teachers exceeded the curricular mandates set by the state and their schools by adding random molecular motion as the driving force for both diffusion and osmosis.

Knowledge Integration and Topic-specific PCK Model

In the science education literature, Van Driel et al. (1998) identify two key elements of PCK integrated during teaching: (1) knowledge of instructional strategies which incorporate representations of subject matter and (2) knowledge of students' learning difficulties. The components of PCK are not independent entities but thoroughly integrated, resulting in the unique form of knowledge for teaching specific concepts in science (Van Driel et al. 1998).

A few researchers in mathematics education literature address the integration of teacher knowledge (Ma, 1999; Ball & Bass, 2003). The literature indicates teachers' content knowledge for teaching mathematics is packaged or bundled with knowledge of learners, representations, instructional strategies, and assessments. Ma (1999) described Chinese teachers as holding a profound understanding of fundamental mathematics packaged with knowledge of learners, representations, and instructional strategies to effectively support students' learning. Similar to Ma's (1999) finding, Ball and Bass (2003) noted teacher content knowledge of mathematics is bundled with knowledge of potential learning difficulties, students' misconceptions, as well as representations and instructional strategies to make the knowledge understandable for students. Ball and Bass (2003) would describe teachers focused on content alone as failing to consider teaching and learning from the perception of mathematics learners. Hristovitch and Mitcheltree (2004) found middle school mathematics teachers focused on content without considering learners' needs and difficulties experienced difficulty in organizing, sequencing, and recognizing prerequisites for learning. Hence, the mathematics education literature emphasizes the importance of content knowledge but recognizes content knowledge

alone is not sufficient for effective teaching. The literature demonstrates a greater awareness of the importance of integrating content knowledge and pedagogy to support students' learning.

Science education literature also addresses the integrated nature of teacher knowledge. Investigating the knowledge for teaching chemistry among experienced teachers, Verloop et al. (2001) described the knowledge, beliefs, and experiences taken from teaching practice, formal teacher preparation, and professional development as intertwined. Hashweh (1985) posited that the PCK of experienced teachers resulted from the integration of subject matter knowledge with their knowledge of students as science learners. Hashweh's (1985) and Verloop et al.'s (2001) descriptions of integrated teacher knowledge were supported by the findings of my study; participants reported varying their instruction to address differences in students' abilities and maturity. The participants in my study were observed teaching the same content which made the integration of the components of their PCK explicit. Hence, the participants packaged their knowledge for teaching diffusion and osmosis to include subject matter knowledge, knowledge of learner difficulties, misconceptions, representations, instructional strategies, and assessment to engage students and support their construction of a conceptual framework for diffusion and osmosis.

The Magnusson et al. (1999) PCK model shows the components of PCK as separate entities only interacting with teacher orientation and not informing one another. After analyzing data from the study, I developed a new model illustrating the integrated nature of PCK for teaching diffusion and osmosis. The model is shown in Figure 28.

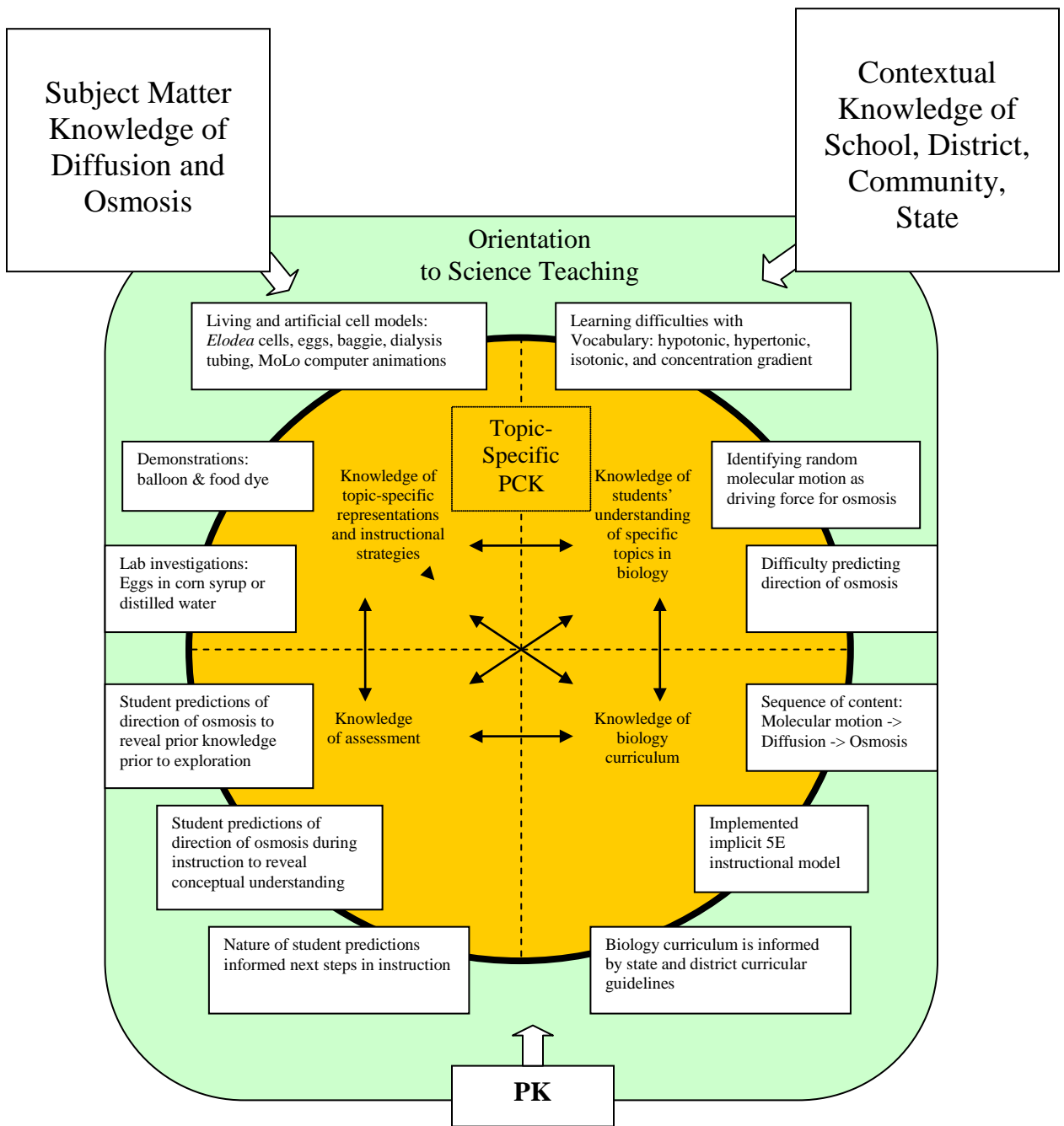


Figure: 28: Model of PCK for teaching diffusion and osmosis

I propose a topic-specific PCK model, drawn as a circle consisting of the four components of PCK. Within the circle, only dotted lines separate the four components of PCK. Interconnecting arrows between all PCK components emphasize the integrated nature of teacher knowledge. Examples of topic-specific representations, instructional

strategies, assessments, and curriculum are included within each PCK component. PCK is embedded within teacher orientation to science teaching to identify the orientation to science teaching as “a conceptual map” (Magnusson et al. 1999, p.97) informing teacher planning and instruction. Subject matter knowledge, contextual knowledge, and pedagogical knowledge (PK) are shown as external influences, each informing teacher PCK for teaching specific topics in science. Hence, this model illustrates the packaging of teacher PCK for teaching diffusion and osmosis.

Implications

In this section I identify and explain the implications of my research. In the following, I explain implications for the preparation of prospective teachers, for professional development of experienced teachers, for research, and for policy.

For Teacher Preparation

One of the major implications for this study relates to the preparation of secondary science teachers. Abell (2007) posits that understanding the development and interaction of subject matter knowledge and PCK is critical for the success of science teacher education. Hence, teacher education must provide opportunities for prospective teachers to observe the practice of experienced teachers. However, knowledge for teaching is often tacit and not easily identified and explained by experienced teachers or understood by novices. Simply observing mentor teachers will not result in the development of PCK among prospective teachers and knowledge gained through methods courses is often viewed as separate from the teaching experience. The literature confirms that PCK develops with teaching experience. Freidrichsen et al. (2009) report effective teacher preparation must include strong mentoring, reflection upon practice,

collaboration among peers to share best practices, and careful consideration of students as science learners.

There are several ways the knowledge gained from this study can inform the preparation of prospective teachers. First, case studies or video case studies of multiple teachers teaching the same topic can be used as teaching tools in methods courses. As prospective teachers analyze teacher and student interactions, matching the goals and purposes of the lesson with students' responses, the tacit nature of teaching and learning is revealed. Prospective teachers must be encouraged to consider teacher cognition and students as science learners rather than focus only on teacher behaviors to explain how students are engaged in learning (Verloop et al. 2002). Second, Loughran, Milroy, Berry, Gunstone, and Mulhall (2001) utilized content representation (CoRe) as a means of capturing and articulating PCK. This approach focuses on the amalgam of content knowledge and teacher PCK to make scientific concepts understandable for students. This approach provides a window into teacher thinking, identifying the interplay between teacher content knowledge and knowledge for teaching. In this study, I used a modified CoRe to represent the experienced teachers' PCK for teaching diffusion and osmosis. Third, it is critical to emphasize the importance of professional collaboration. Knowledge for teaching is not limited to the individual but flourishes with professional collaboration. In my study, professional learning teams were an important source for sharing knowledge and experience for three of the participants. The formation of Professional Learning Teams among prospective teachers within methods classes and continuing into internships fosters the creation of a community of prospective teachers investigating learners, learning, and teaching is critical to effective teacher preparation (Lee & Luft,

2007; Loughran et al. 2001). Fourth, a focus on lesson design (e.g., representations and instructional strategies) as well as learner difficulty provide an excellent vehicle for investigating teaching and learning (Hiebert, Gallimore, & Stigler, 2002; Loughran, Berry, & Mulhall, 2006). Prospective teachers within the context of a professional learning community can bring videos of their teaching to share with their peers. Through reflection upon videotaped lessons and analysis of teacher actions and students' responses, prospective teachers unpack their knowledge and make tacit aspects of their practice more explicit (Loughran et al. 2006). Hence, when prospective teachers develop lessons to teach specific topics, research appropriate representations, demonstrations or laboratory investigations, and consider potential learner difficulties, prospective teachers begin to think about teaching and learning from the prospective of the learner. The findings of this study indicate teacher PCK is highly integrated for teaching specific topics in science. During interviews, study participants unpacked their knowledge for teaching diffusion and osmosis to make their knowledge of students, representations, instructional strategies, assessment, and curriculum explicit. To learn from the practice of experienced teachers, prospective teachers need to study the knowledge of experienced teachers by analyzing videotapes of teachers teaching lessons and developing a CoRe (Loughran et al. 2006) to identify the nature of teacher knowledge and better understand how the components of PCK are integrated during teaching.

For Experienced Teachers

This study examined the PCK of experienced biology teachers for teaching diffusion and osmosis. Experience does not always ensure the development of PCK for science teaching. In this section, I offer several suggestions for supporting the

development of teachers' PCK. First, it is important to note that teaching should not be a solitary endeavor. Teachers' knowledge and practice are enriched by the experience and knowledge of teaching held within a professional community. Three of the teachers in this study were members of Professional Learning Teams (PLT) at their schools and noted the importance of: (a) collaboration with colleagues in the development of curriculum and lesson planning, (b) generation and use of common assessments, and (c) reflection upon teacher's practice and students' learning. Loughran et al. (2001) notes the formulation of a CoRe through teacher collaboration strengthens subject matter knowledge and stimulates the capture, articulation, and sharing of topic-specific PCK among the teachers.

The findings of this study strongly support professional interaction among teachers to promote reflection on teaching practice and student learning. As teachers share their knowledge with colleagues, they are able to identify ways to integrate new strategies and new knowledge of learners into their teaching practice. One recommendation is for teachers to serve as presenters to share their knowledge at professional teacher conferences. Teacher presenters must be encouraged to frame their sessions with a PCK framework. Typically when teachers present at science teacher workshops, the focus is on instructional strategies only. By using a PCK framework, the focus would become broader, to include topic-specific representations, strategies, learning difficulties, assessments, and horizontal curricular connections. By presenting a more integrated model of teacher knowledge, presenters can stimulate the development of topic-specific PCK and integration of teacher knowledge to create effective learning opportunities for students.

For Research

There is a need for additional research on experienced teachers to gain insight into teacher PCK for teaching specific concepts in science. Only by studying reform-oriented experienced teachers can the goal of teaching be clearly articulated for prospective and novice teachers. I found few studies which examined the practice and knowledge of experienced teachers for teaching specific concepts in science. Studies examining specific topics in science education were typically focused on students' learning rather than on teacher knowledge. Research examining the knowledge and practice of experienced teachers teaching specific topics in science would make the nature and integration of teacher PCK explicit. As stated earlier, studies examining the knowledge and practice of teachers for teaching specific topics in science could be used to support teacher learning in teacher preparation programs and in professional development opportunities for experienced teachers. Examining the practice of experienced teachers to capture and articulate their PCK will provide teacher preparation programs with critical knowledge about the nature and integration of the components of teachers knowledge making aspects of this tacit knowledge more explicit and accessible to prospective and novice teachers.

Research which connects studies of teacher PCK to students' learning and achievement would provide important insight into the nature of effective instructional practices. Such studies would be important sources of information for the preparation of prospective teachers and professional development for inservice teachers. This study would be strengthened by connecting teachers' PCK to student achievement. Although this creates an additional burden to the researcher in gaining access to students' test

scores, it would be worth the effort. We need to have topic-specific examples of experienced teachers' PCK that demonstrate this level of PCK is linked to student achievement.

This study does not investigate the development of PCK, instead, the study develops a target goal for teacher knowledge and practice. Research into the knowledge and practice of experienced teachers provides a clear target for the practice of prospective teachers. Hence, additional research linking the practice of novice teachers to experienced teachers would create a continuum of teacher knowledge and practice. By better understanding the continuum from novice to experienced teacher, we can better support the development of PCK among prospective and novice teachers.

For Policy

One of the implications for this study is the necessity for professional development opportunities for teachers. District policy should be altered to support professional development programs for teachers, either through the district or in conjunction with a university. I identify and describe policy changes within school districts which would support teacher learning and, in turn, also enhance student learning and performance.

First, district support of PLTs among teachers within each discipline is important in creating a collegial atmosphere focused on teacher learning and student progress. This study identified the value of PLTs as a means for teachers to develop a common curriculum as well as common formative and summative assessments within each discipline. Three participants in this study were members of a PLT. These teachers emphasized the value of collegial support in planning and teaching within the PLT.

Teachers analyzed summative assessments to reveal students' learning difficulties with content. Hence, the interaction with colleagues within a PLT resulted in increased reflection on teacher practice, fostering PCK development.

Second, school districts should encourage teachers to pursue National Board Certification. Park and Oliver (2008) noted individuals pursuing National Board Certification (NBC) examined and reflected upon their teaching practice in terms of their understanding of students' learning, potential learning difficulties, assessment of students' conceptual understanding, and inquiry-oriented teaching and learning. In my study, Janis identified NBC as an important source of her teacher orientation and PCK. Hence, National Board Certification has two very important benefits; first, it is an indication of teaching as a profession with a unique knowledge base, and second, it focuses teachers to reflect upon and analyze their teaching practice in terms of students' learning (Park & Oliver, 2008).

Third, school administrators must reduce the number of different courses assigned to each teacher. The construction of PCK takes time and requires teachers to focus on their knowledge and practice for teaching specific science content. Hence, teaching a large number of different courses each year hinders the development of PCK, frustrates teachers, and ultimately constrains teacher professional growth and effective teaching practice.

Fourth, school districts should encourage teachers to attend professional conferences by providing financial support for teachers to attend and serve as presenters at state and national professional conferences. By encouraging teachers to reflect on their teaching practice and the practice of other professionals, conferences stimulate the

development of PCK through teacher learning and reflection. Participants in this study identified publications from professional organizations as a source of their PCK for teaching diffusion and osmosis.

Conclusion

In summary, my purpose in this study was to examine the practice and PCK of experienced biology teachers for teaching diffusion and osmosis. By observing the teachers teaching the same concepts, I was able to note differences in their orientations for teaching biology and explore how their orientation to teaching biology informed the teachers' instructional approach and interaction with students. As a former biology teacher, I was able to view biology teachers through the eyes of a researcher rather than those of a practitioner. I found the view to be enlightening; by examining the practice of these six experienced teachers, I was able to gain a clearer understanding of the unique knowledge for teaching identified by Shulman (1987) and consider ways in which the findings of this study can inform teacher preparation and support for inservice teachers. In the following section, I summarize my findings within the perspective of the orientation to science teaching and the components of PCK.

Orientation to Science Teaching

Five of the six participants demonstrated a constructivist orientation to science teaching. Their orientation was informed by their beliefs about learners and learning; hence, lesson design and enactment was informed by the beliefs held by the teacher. Lana believed students were not prepared to conduct explorations of phenomena prior to explanations; this belief resulted in a knowledge-transmission orientation. The findings of

this study emphasize the importance of teacher beliefs and the influence of those beliefs on the nature of instruction enacted by the teacher.

Knowledge of Representations and Instructional Strategies

This study made explicit the use of topic-specific representations for teaching diffusion and osmosis. The teachers used representations as foci for demonstrations and laboratory investigations. All participants challenged students to make and test predictions of the direction of osmosis and/or diffusion. By engaging students with making and testing predictions, the teachers were able to focus the students on specific learning goals for the lesson as well as assess their prior knowledge and conceptual understanding of the concepts.

Five of the six participants in this study implemented an implicit 5E (Bybee, 1997) instructional sequence. During interviews, the teachers explained they engaged students with explorations prior to generating explanations because they believed students would learn most effectively when this instructional sequence was implemented. The teachers drew upon student observations and experiences with the phenomena to develop explanations. This was one of the most unexpected findings within the study. As a former ASTEP supervisor, I often heard interns complain their mentor teachers did not implement inquiry-based instruction into their teaching. Interns may not have recognized the mentor teacher's implicit 5E (Bybee, 1997) instructional sequence without the terminology or references to inquiry.

Knowledge of Students Understanding of Science

The participants identified several student learning difficulties with diffusion and osmosis. All participants identified the unique vocabulary (e.g., hypertonic, hypotonic,

isotonic, concentration gradient) as a significant learning difficulty. The teachers explained students would have difficulty making connections between the vocabulary terms and their observations of diffusion and osmosis. Several participants introduced the concepts prior to introducing the vocabulary terms. Students' ability to accurately predict the direction of osmosis was cited by all participants as a potential learning difficulty. To address this concern, participants engaged students with multiple demonstrations and/or investigations in which students were challenged to make and test predictions of the direction of osmosis. Explanations for the direction of osmosis observed during investigations were generated from students' observations. Identifying and explaining random molecular motion as the driving force for diffusion and osmosis was cited as a potential student learning difficulty cited by participants. Participants used computer animations or whiteboard diagrams illustrating molecular motion to support students' understanding of the role of random molecular motion in diffusion and osmosis. Hence, participant use of representations and instructional strategies reflected their understanding of students as science learners. Adjustments made in their teaching were seamless and only revealed through teacher reflection during interviews.

Knowledge of Assessment

Participants demonstrated an extensive use of formative assessment. All six teachers used student predictions to reveal prior knowledge as well as potential misconceptions prior to teaching and to reveal students' conceptual understanding of phenomena during teaching. Participants also noted the use of simple observations to assess students' understanding and carefully observed facial expressions and body language as a measure of students' understanding. The findings of this study support the

implementation of formative assessments as a means of revealing students' learning difficulties and conceptual understanding of content.

Knowledge of Curriculum

All six teachers exceeded state standards by emphasizing random molecular motion as the driving force for both diffusion and osmosis. The findings of this study support teachers' use of representations which support students' understanding of random molecular motion and collisions as the driving force for diffusion and osmosis.

Knowledge Integration

The knowledge for teaching held by the participants was highly integrated. All participants explained instructional decisions and actions within the context of addressing potential student learning difficulties and revealing misconceptions. Reflecting upon their practice during interviews, participants noted their knowledge of learners informed their use of specific representations and instructional strategies. The use of formative assessments revealed student's prior knowledge and conceptual understanding during the lessons. It is important to note the highly integrated nature of teacher knowledge may not be explicit for prospective teachers. Teacher knowledge must be made explicit for prospective teachers to understand that instructional choices are informed by the teacher's knowledge of learners, potential learning difficulties and misconceptions. This knowledge of learners is then integrated with teacher knowledge of representations, instructional strategies, assessment, and curriculum to engage students with the most effective opportunities for learning.

In summary, I believe ongoing research into the knowledge and practice of experienced teachers for teaching specific topics in science is critical for understanding the development of teacher PCK.

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Appendix A

Observation Research Protocol

Ph.D. Dissertation: Examining the Topic-Specific Pedagogical Content Knowledge of Experienced Biology Teachers for Teaching Diffusion and Osmosis
Lessons are submitted by participants via email 48 hours prior to the pre-observation interview.

Written plan (*purpose: to provide a written guide for the observers*)

I would like to observe your teaching diffusion and osmosis over two class periods. Please send me your plan for these two class periods and answer the following:

- What specifically do you want the students to learn about diffusion and osmosis?
 - Describe what will happen during the beginning, middle, and end of each class. What will you do? What will the students do?
 - How will you know the students learned what you wanted them to learn?
 - Describe what will be needed for these two class periods (e.g., resources, materials, equipment, etc.)
 - Include copies of any handouts, overhead transparencies, assessments, etc. that you plan to use.
-

Prior to first observation (Pre-observation interview):

Researcher role: My role is to assume a stance of empathic neutrality. I am in the field only as an observer. My goal is to understand how participants draw upon their topic-specific PCK when teaching lessons on osmosis and diffusion.

Pre-Observation Interview The purpose of the pre-observation interview is to engage participants in a discussion of their lesson plans during which each participant will explain his/her plans and how the plans will be enacted during the lessons. A second purpose of the pre-observation interview is to explore participants' subject matter knowledge and their topic-specific PCK for teaching diffusion and osmosis.

Opening Questions

1. Tell me what is going to occur over the next 2 days I will be observing you.
 - a. What will I see in Day 1? In Day 2?
 - b. What will you be doing?
 - c. What will the students be doing?
 - d. What are your purposes and goals for these 2 days?
 - e. How did you decide on the purposes and goals for these lessons?
 - f. Tell me about your planning process. What do you do when you are planning what is most important in guiding your instructional decisions?
 - What do you know about your students which informs your planning process?
 - g. Fast forward 2 days. You have successfully taught these two lessons.

- i. What would success look like? How would your students have responded?
- ii. How will you know you've been successful?

Subject Matter Knowledge (SMK)

Say to the participant: One area that I am interested in is your subject matter knowledge for teaching diffusion and osmosis. In the following, I will ask you to explain your own understandings of the content of the lessons you will be teaching.

2. Tell me about your previous experiences teaching diffusion and osmosis.
 - a. How has your approach to this topic changed over time?
 - b. What would you identify as a major source of knowledge for diffusion and osmosis?
 - c. Do you teach this topic independently or do you integrate it into other topics within your biology curriculum?
3. What do you think is important for students to know about diffusion and osmosis?
 - a. Why do you think that is important?
 - b. What else do you know about diffusion and osmosis that students might not need to know?
4. How does diffusion and osmosis relate to other science/mathematical ideas?
5. What instructional decisions did you make when planning these lessons? What knowledge did you draw upon to make these decisions?

Knowledge of Learners

Say to the participant: The following questions are designed to probe what you know about how students might think about diffusion and osmosis.

6. Tell me about the students in this class, in terms of science.
 - a. Describe your students' attitudes towards science.
 - b. What do you know about your students' science abilities that influenced your planning and might also inform your instruction?
 - c. How do you think this particular group of students learn science best?
 - Why do you think that?
 - How do you use your knowledge of students when teaching?
 - d. How have your experiences with students over the years influenced the way you teach?
 - e. How do you motivate students to engage in learning?

7. What do you think students will already know about this topic?
 - Why do you think that they may know that?
 - Do you typically assess student learning at the beginning of a lesson?
 - How do you assess students' misconceptions?
 - Where do you think they may have learned this?

8. Do you expect students to have difficulty with anything that you have planned?
 - a. Why do you think they will have difficulty with that?
 - b. How do you plan to deal with student difficulty?
 - Direct students through algorithms:
 - Explicit guidance or instruction?
 - Guidance through a series of 'directive' questions?
 - Challenge students' thinking:
 - Guidance through a series of questions that lead to conflict and may force students to challenge their ideas?
 - Simply observe but not intervene and allow students to struggle with the uncertainty?

9. How do you believe that students learn best?

10. What will you notice about your students' responses during the lessons that might lead you to alter your plan?

Knowledge of Instructional Strategies

Say to the participant: The next questions will help me to better understand your decisions about representations and instructional strategies you plan to use in your lessons.

11. Tell me how you plan to help students learn the important concepts associated with diffusion and osmosis.
 - What are some examples of teaching activities you have used in the past when teaching this concept?
 - Which of these did you find most effective? Why?
 - Tell me about how you decided upon the instructional strategies you plan to use to teach these concepts during the lessons that I will be observing during your lessons.
 - Did you think of any alternative strategies that could be used during the lesson? If so what else did you consider and when would you decide to implement them into the lesson?
 - Do you consider a 'plan B' if your initial plans do not result in the level of student learning you anticipated?

12. Tell me about you plan to implement into your teaching of diffusion and osmosis.
- How do you plan to start the lessons on Day 1 and 2?
 - Did you consider starting the class in a different way? Why/why not?
 - Explain the body of the lessons, what will you be doing and what will your students be doing?
 - Are there other factors which influenced your planning decisions?
 - How do you plan to engage the students with lesson content?
 - How do you plan to draw out student ideas concerning observations of osmosis and diffusion?
 - How do you think you might change your plans if students do not respond well to your questions?
 - Do you often change your plans ‘on the fly’ in response to student responses?
13. Tell me about the representations you decided to use in your lessons.
- How will you integrate the representations into your teaching?
 - What led you to use the representations in this way?
 - Have you used other representations in the past? Were they as successful?
 - Did you consider representing the topic of OSMOSIS AND DIFFUSION in another way?

Knowledge of Curriculum

Say to the participant: These next questions are designed probe your ideas about the biology curriculum and where your ideas for these two lessons came from.

14. Tell me how you decide upon the content of your lessons. In other words, how do you decide what to teach?
- Tell me about the materials (lecture notes, handout, transparencies) you prepared.
 - Where did the materials (lecture notes, activities, worksheets, etc.) come from?
 - What modifications did you make to these materials?
 - Tell me about your use of the Internet as a resource.
 - What did you hope that your students would learn from this?
 - How did you incorporate this into your teaching?
 - How do you intend to sequence your instruction in the lessons?
15. I have some questions for you related to how these plans relate to other topics that you might teach.
- How do you see these two lessons relating to one another?
 - How do these 2 days of instruction fit into the unit you currently are teaching?
 - How does that math/science fit into the bigger picture of what students learn in this class?
 - How does (this topic) fit into the “big picture” of what students learn about math/science in middle school/high school?

Knowledge of Assessment

Say to the participant: The last area I want to ask you about is how you will know what students learn from these two days of class.

16. During the 2 days of instruction, what do you plan to assess? Why do you think it is important to assess this?
 - a. How will you determine if students understand the concepts portrayed in the video on cell functions?
 - b. How do you plan to assess student understanding?
 - Describe how you will find out if students learned what you intended?
 - What assessment strategies have you found to be most effective?
 - Where did you learn about those assessment strategies?
 - How have you refined your assessment strategies to more accurately assess student understanding?
 - What will you do with the information you gain from assessment?
 - c. How do student responses influence 'on the fly' decisions about content or instructional strategies during a lesson?
 - d. How are your decisions about lesson content and activities influenced by state and district assessments?

17. At the end of the day when students have left and you have time to reflect upon the goals and outcomes for the lesson, do you make changes that will be implemented the next time you teach that lesson?
 - a. What criteria do you use to evaluate your planning and teaching?
 - b. What do you base your decisions upon when you decide to change the goals, content, instructional strategies, or assessments implemented within a lesson?

During the observation:

- The researcher will select several occurrences during the course of each lesson to use as a basis for reflection and questions during the Stimulated Recall Interviews.
- Video instances with focus on participant knowledge of:
 - Representations and instructional strategies
 - Students' understanding of science
 - Assessment
 - Curriculum

After each observation:

Stimulated recall interview (*purpose: to have the intern immediately reflect on the instruction as a window into SMK and PCK and connect to pre-interview*).

Stimulated Recall Interview

18. How do you think the lesson went? In what ways was the lesson I observed different than other periods you taught it? Different from your plans?
19. I have selected some parts of the instruction I found particularly interesting. I want to watch them together and ask you some questions about them.
20. Let's watch this part (interviewer asks questions starting in one of the following categories based on the reason for selecting the specific interesting instance).
 - a. What were you thinking when this was occurring? Tell me more about what was happening when you _____.
 - b. Was there a time during the instruction when you changed your plan? Tell me about that.
 - c. [K of Learners] What do you think the student was thinking? Why do you think the student was having difficulty at that point? What knowledge about students did you use to make instructional decisions? In what ways, did students influence your teaching decisions today?
 - d. [K of Instructional Strategies] Tell me about that (example/analogy/activity/lab)? Why did you decide to use that? How did this teaching strategy help you achieve your overall goals? Where did you learn to teach it that way?
 - e. [K of Curriculum] Did the activities achieve the purpose you intended? Why do you think that? How did your curriculum materials support or hinder you in implementing your plan?
 - f. [K of Assessment] What do you think students got out of the lesson? How do you know? Tell me about how you found out about student learning. Why did you decide to do that? Where did that idea come from? How do you think it worked?
 - g. [SMK] Given the opportunity to sit down with a colleague you trust, what questions would you ask about diffusion and osmosis?
 - h. [SMK] What were the critical science ideas in today's lesson?

The following questions focus specifically on the orientation to science teaching.

21. [Orientations]. Imagine your best day of teaching science/mathematics.
 - a. Describe what makes it a "best day" for you.
 - b. How do these two lessons that you've taught compare to your "best day" description.

22. [Teachers' orientations to science teaching]. Now I would like you to consider a typical day of teaching.
- a. What do you perceive as the teacher's role in a typical lesson?
 - b. What do you perceive as the students' role in a typical lesson?
 - c. How do you prefer to teach? Explain your answer.
 - d. How do you think your teaching is influenced by your colleagues?
 - e. In what ways have your ideas about teaching changed over the years you have been teaching. Probe for sources of these changes.
 - f. How do you think you learn science best? How do you think your perception of yourself as a science learner influences your teaching?

Appendix B

PRINCIPAL CONSENT FORM

Ph.D. Dissertation: Examining the Topic-Specific Pedagogical Content Knowledge of Experienced Biology Teachers for Teaching Diffusion and Osmosis

My name is Deanna Lankford and I am beginning my dissertation study researching how experienced teachers draw upon their knowledge of teaching to make instructional decisions. Ultimately, I want my work to provide insight into the practice of experienced teachers to inform science teacher educators.

INFORMATION

The study I plan to conduct involves observing experienced teachers, selected by the University to serve as mentors for ASTEP interns, teaching two consecutive lessons focused on a topic in cell biology. Study participants will have an opportunity to reflect upon their planning and teaching during three interviews conducted prior to teaching and following each of the lessons observed. This individual is an experienced and accomplished biology teacher selected to serve as a mentor teacher by the University for student interns in the ASTEP teacher preparation program. Participation in this research is totally voluntary with no penalty or consequence for electing not to participate or for withdrawing from the study at any time.

PARTICIPATION

Participation in the study will result in the participant agreeing to:

1. Allow the researcher to observe and videotape the participant teaching one class on two consecutive days. These observations will occur during the fall semester of 2008 and require the following:
 - (a) The development and submission of written lesson plans for two consecutive lessons designed to teach concepts as defined by:
 - i. Course Level Expectation 3:2:F – Cellular activities and responses can maintain stability internally while external conditions are changing (homeostasis).
 - (b) An interview prior to the lesson observation during which I will ask questions about teacher knowledge and beliefs concerning teaching, learning, and learners.
 - (c) Observation of the lessons by the researcher.
 - (d) A post observation interview following each observation during which the teacher will be asked to respond to questions about the lesson and instructional decisions made during the planning and teaching of the lesson.

BENEFITS

Teacher participation in this research study will provide important insights into how experienced teachers draw upon their knowledge of teaching to make instructional decisions during planning and teaching. This insight into teacher knowledge and decision

making of experienced teachers has the potential to inform teacher educators and enhance teacher preparation programs.

CONFIDENTIALITY

Teacher identity will be kept strictly confidential. Pseudonyms will be used in all published documents and the name and location of your school and school district will not be revealed. Only the researcher will know the participant’s identity. The data collected during the study will be stored in a secure area. The teacher may choose to end participation at any time during the study, and, at that time, all related data will be destroyed. Data will be stored for three (3) years beyond the completion of the study and at that time it will be destroyed.

RISKS

This project does not involve any risks greater than those encountered in everyday life. This project has been reviewed and approved by the University Human Subject Review Board. The Board believes the research procedures adequately safeguard your privacy, welfare, civil liberties, and rights. For additional information regarding human subject participation in this research, please contact the University IRB officer.

CONSENT

Please read the consent statement below and place an “x” next to the statement that describes your desire to participate in this study at this time. Sign and date the form.

I have read the information presented above and have had an opportunity to ask questions and receive answers pertaining to this project.

_____ I have been informed of this study and agree to allow this research study to be conducted in my building. I am aware that participation is voluntary and that the teacher is free to withdraw participation at any time without penalty.

_____ I have been informed of this study and do not agree to allow this research study to be conducted in my building.

Signed: _____ Date: _____

Printed Name: _____

Researcher: _____

Deanna Lankford

Research Supervisor: _____

Dr. Patricia Friedrichsen

Appendix C

TEACHER INFORMED CONSENT

Ph.D. Dissertation: Examining the Topic-Specific Pedagogical Content Knowledge of Experienced Biology Teachers for Teaching Diffusion and Osmosis

My name is Deanna Lankford and I am beginning my dissertation study researching how experienced teachers draw upon their knowledge of teaching to make instructional decisions. Ultimately, I want my work to provide insight into the practice of experienced teachers to inform science teacher educators.

INFORMATION

You must be at least 18 years of age to be eligible to participate in the study. Your participation in this study is voluntary; you may choose not to participate and there will be no penalty or consequence to you. If you decide to participate, you may withdraw from the study at any time without penalty.

PARTICIPATION

If you decide to participate, you will agree to:

2. Allow the researcher to observe and videotape you teaching one class on two consecutive days. These observations will occur during the fall semester of 2008 and require the following:
 - (a) The development and submission of written lesson plans for two consecutive lessons designed to teach concepts as defined by:
 - i. Course Level Expectation 3:2:F – Cellular activities and responses can maintain stability internally while external conditions are changing (homeostasis).
 - (b) An interview prior to the lesson observation during which I will ask you some questions about your ideas concerning teaching, learning, and learners.
 - (c) Observation and videotaping of the lessons. The participant is responsible for collecting informed consent forms from the students enrolled in the class being videotaped.
 - (d) A post observation interview following each observation during which you will be asked to watch segments of the video and respond to questions about the lesson and instructional decisions made during the planning and teaching of the lesson.
3. Allow the research team to display video clips at professional research conferences and other professional meetings. (Your image may appear in these clips.)

BENEFITS

Your participation in this research study will provide important insights into how experienced teachers draw upon their knowledge of teaching to make instructional

decisions during planning and teaching. This insight into teacher knowledge and decision making of experienced teachers has the potential to inform teacher educators and enhance teacher preparation programs.

CONFIDENTIALITY

Your identity will be kept strictly confidential. Pseudonyms will be used in all published documents and the name and location of your school and school district will not be revealed. Only the researcher will know your identity. The data collected during the study will be stored in a secure area. You may choose to end your participation at any time during the study, and your data will be destroyed. Data will be stored for three (3) years beyond the completion of the study and at that time it will be destroyed.

RISKS

This project does not involve any risks greater than those encountered in everyday life. This project has been reviewed and approved by the University Human Subject Review Board. The Board believes the research procedures adequately safeguard your privacy, welfare, civil liberties, and rights. For additional information regarding human subject participation in this research, please contact the University IRB officer.

CONSENT

Please read the consent statement below and place an “x” next to the statement that describes your desire to participate in this study at this time. Sign and date the form.

I have read the information presented above and have had an opportunity to ask questions and receive answers pertaining to this project.

_____ I hereby agree to participate in this research study. I am aware that my participation is voluntary and that I am free to withdraw participation at any time without any penalties to myself.

_____ I do **not** agree to participate in this research study.

Signed: _____ Date: _____

Printed Name: _____

Researcher: _____

Deanna Lankford

Research Supervisor: _____

Dr. Patricia Friedrichsen

Appendix D

STUDENT RELEASE FORM:

PhD. Dissertation

Ph.D. Dissertation: Examining the Topic-Specific Pedagogical Content Knowledge of Experienced Biology Teachers for Teaching Diffusion and Osmosis

I am a graduate student completing a doctoral degree in science education. My doctoral research will investigate how experienced biology teachers plan and teach lessons. As part of the study, I will be videotaping your biology teacher and, as a result, your image may be captured on videotape. I am seeking your permission to analyze the content of the videotapes in which your image is captured.

Information: Your participation/release is voluntary; you may choose not to participate and there will be no penalty or consequence. You may view data at any time and request that certain information not be used.

If you sign yes on this form, you give permission for the research team to:

1. Capture your image on videotape, and analyze the content of the videotapes for research purposes.
2. Display clips at professional research conferences and other professional meetings. (Your image may appear in these clips.)

Privacy: No names or identifying information will be used in reporting the research findings on written documents. However, your image may appear in a video clip displayed at professional research conferences and other professional meetings. (You may view videotapes at any time and request that certain video clips not be used).

Risks: This project does not involve any risks greater than those encountered in everyday life. This project has been reviewed and approved by the University Human Subject Review Board. The Board believes the research procedures adequately safeguard your privacy, welfare, civil liberties, and rights. For additional information regarding human subject participation in this research, please contact the University IRB officer.

Consent: I have received and read a copy of this form. I understand the above information.

- Yes, I agree to participate. I understand that I can change my mind and withdraw from the project at any time. I understand that I may request that certain information not be used.
- No, I will not participate. If your image is captured on video while in the classroom, it will not be displayed or analyzed for research purposes.

Student Signature _____ Date _____

Name (*please print*) _____

Parent Signature _____ Date _____

Appendix E

Lesson Plan Request

Ph.D. Dissertation: Examining the Topic-Specific Pedagogical Content Knowledge of Experienced Biology Teachers for Teaching Diffusion and Osmosis

As a participant in this study, you will submit two consecutive lesson plans for teaching the topics of diffusion and/or osmosis. When developing your lesson plans please note the Course Level Expectation 3:2:F – Cellular activities and responses can maintain stability internally while external conditions are changing (homeostasis).

Your lesson plans will provide a written introduction and guide for my observation of your lessons. Please respond to the following prompts in your lesson plans:

- What do plan to teach in the lessons?
- Describe what will happen each day (beginning, middle, and end of class) as you teach these two lessons.
- Describe the materials you will use to teach the lessons.
- Please include any handouts, overhead transparencies, or PowerPoints you plan to use.

Please contact me if you have any questions regarding this request or about your participation in this research.

VITA

Deanna Lankford was born and raised in St. Louis, Missouri. She earned a Bachelor's degree with a double major in education and biology from Southeast Missouri State University in Cape Girardeau, Missouri. Deanna taught physical science at Mehlville Junior High School before relocating to Blue Springs, Missouri. In Blue Springs, Deanna worked as a full time junior high science teacher for five years teaching physical science. At the close of the fifth year of full time teaching, Deanna left to raise her two daughters. She returned to the Blue Springs School District to teach tenth grade general biology and earn a Master's Degree in Teaching Arts from Webster University. Deanna earned National Board Certification in Adolescent and Young Adult Science in 1998 and won the Presidential Award for Excellence in Science Teaching in 2000.

In 2003, Deanna retired from teaching, relocated with her husband to Rocheport, and entered graduate school at the University of Missouri. Deanna's assistantship included serving as a supervisor for interns in the Alternative Certification Program (ACP) and as a Graduate Teaching Assistant (GTA) for Dr. Fred vom Saal. In 2005, Deanna won the Graduate Teaching Assistant of the Year Award and became a Graduate Research Assistant (GRA) investigating teacher learning among ACP interns. In 2005, she earned a Education Specialist Degree in Science Education and entered the Science Education Doctoral Program while continuing with the GTA and GRA assistantships. Deanna completed her doctoral degree in the spring of 2010 with Dr. Patricia Freidrichsen as her dissertation advisor. Deanna's future plans include working through the Office of Science Outreach to design professional develop and learning opportunities for Missouri teachers and high school students.