PARTICULATE NATURE OF MATTER, SELF-EFFICACY, AND PEDAGOGICAL CONTENT KNOWLEDGE: CASE STUDIES IN INQUIRY

by Kathryn Marie Nafziger

In many classrooms, elementary teachers focus their efforts on literacy and frequently marginalize science instruction. In order to increase time spent teaching science, a local school district initiated a program that coupled literacy with standards-based, inquiry science instruction. Utilizing a qualitative, case study approach, this research explored how teaching physical science through inquiry affected teachers’ knowledge of the particulate nature of matter, self-efficacy, and pedagogical content knowledge. The results of the inquiry revealed that a sound understanding of good inquiry practices did not always translate to practice, that teaching through inquiry with prior knowledge of the particulate nature of matter can uncover gaps in this knowledge, and that self-efficacy was only influenced by the teachers’ knowledge of the particulate nature of matter if the teacher understood the connections between this knowledge and their teaching practice.
PARTICULATE NATURE OF MATTER, SELF-EFFICACY, AND PEDAGOGICAL CONTENT KNOWLEDGE: CASE STUDIES IN INQUIRY

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Chapter 1: Statement of the Problem

For many students, the first formal opportunity to study chemistry occurs during high school; however, such a course is not likely to be the students’ first experience learning about matter. In many states across this country, instruction about the nature of matter may begin as early as kindergarten.\textsuperscript{3,4} Even at that point, however, students are not the “blank slates”\textsuperscript{5} many believe as evidenced by the fact that there exists a differentiation in the minds of infants between an object and the materials from which that object is made.\textsuperscript{6}

In America’s school systems, children are taught to read and write in elementary school, and therefore, literacy is the primary focus of instruction for many teachers. As a result, science instruction is marginalized in many classrooms. Indeed, in the state of Ohio, science is not tested on the Ohio Achievement Tests\textsuperscript{7} until fifth grade – the third such year students’ knowledge is assessed using this instrument. Teachers often feel pressured to “teach to the test”\textsuperscript{8} and subsequently focus much of their teaching those subjects that are tested, language arts and mathematics. In a practical sense, therefore, this means that some students in the state of Ohio may not have regular science instruction until the fifth grade. It is in the early elementary grades where the foundations of learning take place, and thus in terms of chemistry, it is crucial for students to have quality science education, specifically about the nature of matter – a concept which permeates all future chemistry instruction.

Because of the importance in establishing a solid science understanding in the elementary years, the school district, which served as the focus of this research, was interested in creating meaningful science experiences for its elementary school students. To help in this process, a partnership between Miami University and the district formed in 2005 with the objective of finding ways of pairing the teaching of literature with science. This incorporation utilized a framework for inquiry called the 5E learning cycle,\textsuperscript{9,10} where reading science trade books became a stage of the inquiry cycle.

Considering the pivotal role teachers play in student learning during the elementary grades, this research focused on documenting the experiences of three teachers’ as physical science was taught through inquiry-based, 5E learning cycles. This documentation was completed through case studies. The research questions that guided this inquiry are: how does teaching science through inquiry affect teachers’
• knowledge about the particulate nature of matter?
• self-efficacy about teaching science?
• pedagogical content knowledge about teaching science through inquiry?

By answering these questions, the researcher hoped to learn about the individual teacher’s experiences in implementing the 5E learning cycles created through the partnership. It was of particular interest to learn about the impact of the 5E learning cycles on the teacher’s knowledge about the particulate level of nature. For the school district, answers to such questions could help provide better support to the elementary teachers as they used the new science resources available to them, and perhaps, even increase the frequency with which science is taught. Finally, for the audience-at-large, this study contributed to refining the case study approach and expanded the conceptions about what elementary teachers know about the particulate nature of matter, their self-efficacy for teaching science, and their pedagogical content knowledge.
Chapter 2: A Review of the Literature

Introduction

This chapter presents the literature pertinent to the research involving the particulate nature of matter, efficacy, and pedagogy in kindergarten and first grade. The theoretical framework and research questions provide the preface for this review of the literature.

Theoretical Framework

The learning of knowledge takes place everyday, but how is learning achieved? The theory of constructivism is an epistemology where individuals actively construct knowledge.\textsuperscript{11, 12} This knowledge that is constructed in the mind has many varieties. It must be noted, though, that all learning of knowledge is not created equal. Learning is on a continuum between rote learning and meaningful learning. Rote learning occurs when new information is simply memorized without making connections to prior knowledge or when there is no prior knowledge available for making connections to the new information.\textsuperscript{12} In order for learning to be meaningful, there are three requirements.\textsuperscript{1, 11, 12} First, the learner must obtain some relevant prior knowledge in order to incorporate the new knowledge. Secondly, the material to be learned must be meaningful, which means “it must contain important concepts and propositions relatable to existing knowledge.”\textsuperscript{1} The final requirement for meaningful learning is the student must make a conscious and deliberate decision to learn meaningfully; that is “to non-arbitrarily incorporate this meaningful material into his/her existing knowledge.”\textsuperscript{1} A concept map of these requirements for meaningful learning is shown in Figure 1.

Novak saw the need to develop a theory of education in which the nature of knowledge and the nature of human learning were brought together.\textsuperscript{12} Novak suggested that successful education entailed the “acquisition of knowledge (cognitive learning), change in emotions or feelings (affective learning), and gain in physical or motor actions or performance (psychomotor learning) that enhance a person’s capacity to make sense out of their experiences.”\textsuperscript{12} Novak’s theory of education is termed Human Constructivism, and states, “Meaningful learning underlies the constructive integration of thinking, feeling, and acting leading to empowerment for commitment and responsibility.”\textsuperscript{12} Central to this notion of meaningful learning was Novak’s belief that “the central purpose of education is to empower learners to take charge of their own meaning making.”\textsuperscript{12}
Research Questions

Within the context of the elementary grades, the researchers focused upon the following question. Does teaching science through inquiry promote meaningful learning for teachers? To operationalize the definition of Human Constructivism in the research study, the choice was made to study teacher knowledge of the nature of matter (cognitive), teacher efficacy (affective), and teacher knowledge of inquiry (cognitive and psychomotor). Specifically the research questions that governed this study were how does teaching science through inquiry affect teachers’

- knowledge about the particulate nature of matter?
- self-efficacy about teaching science?
- pedagogical content knowledge about teaching science through inquiry?
In order to choose our data collection and analysis methods, a review of the literature regarding the particulate nature of matter, teacher efficacy, pedagogical content knowledge, and elementary science was conducted and summarized herein.

**Particulate Nature of Matter**

Teachers struggle to teach physical science content through inquiry, in particular due to their science content preparation. The National Research Council\(^{13}\) explained, “To teach their students science through inquiry, teachers need to understand the important content ideas in science…They need to know how the facts, principles, laws, and formulas that they have learned in their own science courses are subsumed by and linked to those important ideas” (p. 92). Therefore, it was seen as an important part of this research to assess what the teachers knew about science, specifically the particulate nature of matter. Harrison and Treagust\(^{14}\) have studied misconceptions in the particulate nature of matter and define construct this way: “[i]t involves the particulate theory (often now called the kinetic molecular theory), which is the basis of explanations of atomic structure, bonding, molecules, much of solution chemistry and chemical reactions, equilibrium and chemical energetics…that all matter is composed of discrete, energetic particles that are separated by space” (p. 190). Yezierski explained in her article about the use of computer animations and their impact on students’ conceptions of the particulate nature of matter (PNM) that “[u]nderstanding the particulate nature of matter is critical to understanding chemistry.”\(^{15}\) It is important for teachers to have adequate knowledge of the particulate nature of matter. The National Research Council provided three possibilities for learning major science concepts, which included (1) formal pre-service or in-service classes, (2) independent programs of study, and (3) serious reflection on teacher interactions with students in their inquiry based classrooms.\(^{13}\) This idea of serious reflection on interactions with students in the inquiry-based classroom was a driving force of this project.

The National Research Council has published the *National Science Education Standards*.\(^3\) Standards, on both the national and state levels, were created to ensure every student has the opportunity to learn the concepts. The kindergarten through fourth grade physical science standards include concepts and principles under the headings Properties of Objects and Materials, Position and Motion of Objects, and Light, Heat, Electricity, and Magnetism. The focus of this research is the particulate nature of matter and, therefore, was interested in the
Properties of Objects and Materials. The standards under this heading for kindergarten through fourth grade are stated in Appendix A. The state of Ohio also broke down the physical science standards within the Academic Content Standards\textsuperscript{4} and has specific indicators titled the “Particulate Nature of Matter” for each grade level. These are listed in Appendix B for kindergarten and first grade.

There are numerous studies on students and teachers’ knowledge of science, nature of science, and the particulate nature of matter. Gabel, Samuel, and Hunn\textsuperscript{16} looked at pre-service elementary teachers’ misconceptions about the particulate nature of matter and possible reasons for them from the literature. If teachers have misconceptions, the misconceptions will be taught to students or these imperative concepts will be avoided altogether. It is argued among educators when the particulate nature of matter should be introduced to students. Gabel, Samuel, and Hunn explained that “[t]he ability to represent matter at the particulate level is important in explaining phenomena or chemical reactions, changes in state and the gas laws, stoichiometric relationships, and solution chemistry. It is fundamental to the nature of chemistry itself.”\textsuperscript{16} They argued that the microscopic level was represented in elementary science textbooks and elementary teachers should be familiar with the concept to understand their every day observations and the concepts taught students, and hence should be included in their pre-service elementary teachers’ Basic Skills Course at Indiana University. “An additional reason for inclusion of the topic is to show students how theories and models are an outgrowth of the other science process skills of observation, inferring, predicting, hypothesizing, experimenting, etc.”\textsuperscript{16} Gabel, Samuel, and Hunn conducted the study to “determine prospective elementary teachers views of the particulate nature of matter before instruction on the topic” through a 14-Item Nature of Matter Inventory. It was found that “sixty percent of the students enrolled in the Basic Science Skills course had a previous course in high school or college chemistry[, y]et their conceptions of the particulate nature of matter [were] far from desirable.”\textsuperscript{16} The conclusion drawn was that “although chemistry courses must touch upon the particulate nature of matter to some degree, instruction is insufficient to bring students to a high level of understanding on most attributes.”\textsuperscript{16}

Kruse and Roehrig\textsuperscript{17} conducted a study of forty-five chemistry teachers’ conceptions of chemistry within a diverse urban district. The study employed the Chemistry Concepts Inventory\textsuperscript{18} to assess the teachers’ chemistry knowledge, most specifically about transformations of matter. The data collected from this inventory were analyzed in conjunction with the
participants’ background information. The findings of the study pertinent for this research are that “teachers have often not been exposed to situations that challenge the validity of their constructed ideas, and thus they may be unaware of their own misconceptions, much less see a need to provide such meaningful situations to their students.” It was also found that “a lack of formal instruction, experience, or comfort teaching conceptual chemistry may result in a teacher teaching the content superficially, or not at all, leading to limited opportunities in which both teacher and students can test the validity of their constructed ideas.”

A study completed by Boo determined Grade 12 students’ understandings of chemical bonds and the energetics of reactions. Using five familiar chemical reactions, the researcher conducted interviews with 48 students. It was found that “the main problem is that students have not learned the why and how of chemical change.” Boo stressed that emphasis must be on the driving force of a chemical change; “otherwise, chemical change, and hence much of chemistry content, could be seen as magic or unpredictable.” Boo calls for more emphasis on “the conceptual and conjectural nature of ideas.” During the study, a problem arose that “the vast majority of the students were unable to use a framework (whether scientific or alternative) consistently across the five events” and could not see that nature of scientific concepts and principles are applicable “across the entire range of chemically diverse phenomena.”

These studies are important and significant, but what about the particulate nature of matter in reference to elementary grades? As stated earlier, Gabel argued the point for the particulate nature of matter within a class for pre-service elementary teachers. The Committee on Science Learning provided more insight into this matter:

> Although very young children tend to identify material kinds by their perceptual properties, during elementary school children increasingly trace the identity of materials through their transformational history (e.g., sawdust comes from grinding up wood, so it must still be the same kind of stuff with some of its properties). This move can lead them to ‘hyperconservation of material kind’—a commitment to thinking that the identity of material is generally preserved which prevents them from being able to engage with the idea of chemical change. (p. 101-102)

Children are not a “blank slate” and require conceptual changes or modifications to gain better understandings of the world because they “search for mechanisms and the important ways ideas about mechanisms inform their reasoning and inference in everyday life.” These mechanisms
created by children help them to understand the world but are many times incomplete or faulty,\textsuperscript{6} and must be identified by teachers. Once identified, teachers must be able to provide science-learning opportunities for students to improve their understanding, which requires a deep understanding of the content by the teacher.\textsuperscript{13,16} In light of all this, it was important to remember that elementary teachers are generalists rather than content specialists. This lends to their science knowledge being weak, and their science pedagogical content knowledge may be seen as the enacting of the knowledge bases developed in the teaching of a range of subjects.\textsuperscript{20,21}

**Self-Efficacy**

Student learning is the prominent concern in education and influenced by the teachers’ ability to present the concept. Due to the key role teachers play in education, student learning is also impacted by a teacher’s self-efficacy. Bandura\textsuperscript{2} described self-efficacy as “beliefs in one’s capacity to organize and execute courses of action required to produce given attainments.” Gabel described the construct with regard to chemistry teachers in that “self-efficacy describes a belief in the ability to, and the likelihood of, affecting a situation in a desirable fashion.”\textsuperscript{22} Bandura\textsuperscript{23} split the construct into efficacy expectations, later termed perceived efficacy, and outcome expectations. Perceived efficacy is “the conviction that one can successfully execute the behavior required to produce outcomes.”\textsuperscript{2} Outcome expectancy is “a person’s estimate that a given behavior will lead to certain outcomes.”\textsuperscript{2} The relationship between these two constructs is shown in Figure 2. These two dimensions had to be differentiated due to the fact that merely believing in outcomes of a certain behavior does not mean there is also a belief that the individual can actually execute it. For example, a chemistry student could firmly believe in the use of a laboratory experiment to determine the rate of a reaction, but that same student could also not believe in his or her own capabilities to perform the experiment due to inexperience.

![Figure 2](image.png)

*Figure 2.* The relationship between efficacy beliefs and outcome expectancies.\textsuperscript{2}
Teacher efficacy is applying the idea of self-efficacy to the field of teaching. It is “the extent to which teachers believe they can influence student learning.”24 “Most broadly, ‘teacher efficacy’ refers to teachers’ beliefs in their ability to influence valued student outcomes.”25 Each definition contains a form of the word “belief” or “conviction” and according to Enochs and Riggs,26 “beliefs are part of the foundation upon which behaviors are based.” Therefore, teacher efficacy will have implications on the decisions teachers make about how they will construct their classroom.

Cannon explained that teacher efficacy is an important attribute in effective science teaching.24 Enochs and Riggs26 explained that efficacy beliefs “may account for individual differences in teacher effectiveness.” These efficacy beliefs can be influenced by many of factors, which may include but are not limited to gender, content area, and professional standing.24 Bandura23 noted that teachers with high levels of self-efficacy and outcome expectancy beliefs “should persist longer and provide a greater academic focus in the classroom.”2 Bandura also discussed the concept of the capability of teachers by explaining that beliefs are only significant if they can be executed. He further explained that efficacy determines how people handle difficult tasks because self-doubt can weaken even the most capable. Enochs and Riggs26 found that “elementary teachers’ perceptions concerning their qualifications for teaching science were consistent with the amount of time they spent teaching it.” Woolfolk, Rosoff, and Hoy27 described implications of low efficacy for teachers. “For a teacher with a low efficacy, they will feel the desire to take control of classroom behavior and use negative sanctions to increase students performance.”27 This could have serious implications on a teacher’s choice to implement inquiry activities and to allow the students to freely explore concepts.

Waters-Adams conducted a case study of four teachers to determine their understanding of the nature of science and their classroom practices. “None of the teachers considered themselves to be specialists in science.”28 Waters-Adams believed that “an understanding of the dynamics of the teachers’ action, or of the relationship between that action and their views of the nature of science, is inadequate unless consideration is also given to the teachers’ general beliefs about education.” This inadequacy was due to the fact that “the teachers seemed to have confidence in their resulting practice only when it accorded with elements of their deeply held beliefs about appropriate pedagogy.”28 In this case study, the teachers saw their success in
science teaching when confident, which “was greatly increased if they could sense a congruence between the three elements: beliefs, teaching, and understanding of science.” Since elementary teachers switch between subjects all day, these teachers begin to rely on core beliefs about education. Therefore, in order to understand the practice of a teacher, a “consideration of their wider beliefs about teaching, learning, and curriculum” must be addressed. It was found that these beliefs are consistent and resilient to change. The study concluded that confident and effective teaching must not only come from subject matter knowledge, but also teaching practices agreeing with the individual’s beliefs. These findings must be kept in perspective, though, because they are not the only element influencing action. The study also described “understanding at a theoretical level does not predict eventual practice.” This is similar to an experience Mazur witnessed in his Harvard physics classroom where students had a sound understanding of the theory in introductory physics but struggled to relate this knowledge to conceptual questions.

Even the skeptical see efficacy as a positive construct, though Wheatley calls for a “reconceptualization.” He sees that it is not clear how to use all the research on teacher efficacy in teacher education. “This reconceptualization is needed in order to provide useful understanding about educational approaches in which power relationships are transformed, and learners take a more active role in their own learning.” Wheatley calls for more than describing teachers as merely having a high or low teacher efficacy, because teacher efficacy is a “continuous variable.” There are definitely problems with efficacy scales, which include ambiguous wording, lack of subject matter context making interpretation of a moderately confident response difficult, and uncertainty about the students in the questions. Wheatley also pointed out that teacher efficacy has potential to inhibit teachers from learning about and implementing “democratic teaching practices”, such as the inquiry. He is also concerned that “teachers could give themselves the highest self-ratings possible on the [efficacy surveys], yet teach in traditional, teacher dominated ways.” This is a valid concern, but it has also been found that “teachers with high self-efficacy concentrate on individualized instruction, adapt teaching practices to student needs, are more likely to use hands-on teaching methods, and are more involved in collaborative activities with others.” Therefore, scores of high self-efficacy on a survey could mean a variety of realities for that teacher’s practices. In order to gauge the
reality of the efficacy of the teacher’s within this study, the researchers collected data from multiple sources.

In one study conducted by John Settlage,31 a Learning Cycle Test was used to determine the teachers’ knowledge of the learning cycle. It was found that a teacher’s “belief in their ability to shape the science learning of their future students did accurately predict their performance on the Learning Cycle Test.” Settlage also found that “a confidence in one’s ability to positively affect students’ learning serves as a strong predictor of performance on the Learning Cycle Test. Higher outcome expectancies compellingly forecast heightened understandings of the learning cycle.” It was concluded with “cautious optimism” that instruction about the learning cycle contributes to a pre-service teachers’ self-efficacy.

It is important for teachers to have adequate knowledge of the particulate nature of matter for teaching, a confidence teaching the elementary science, and also appropriate knowledge of the pedagogy for teaching science.

**Pedagogical Content Knowledge**

Pedagogical content knowledge is a construct that has been used in creating policy for teachers, designing teacher education programs, and research that has focused upon classroom teaching.32 This began in 1986, at a time when the legitimacy of teacher education and professionalism was being questioned. Shulman discussed a gap, termed “the missing paradigm,” in research on the knowledge of teachers. Shulman acknowledged that much was known about how teachers manage their classrooms, organize activities, allocate time and turns, structure assignments, ascribe praise and blame, formulate the levels of their questions, plan lessons, and judge general student understanding.”33 What was missing from the research was “questions about the content of the lessons taught, questions asked, and the explanations offered.”33 In order to better describe this gap, Shulman drew a distinction among content knowledge, pedagogical content knowledge, and curricular knowledge. Pedagogical content knowledge (PCK) was one focus of the current research and will be discussed further. Shulman explained PCK as “the dimension of subject matter knowledge for teaching.” PCK is “the ways of representing and formulating the subject that make it comprehensible to others.”33 The construct of PCK includes another aspect of the “the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations.”33
PCK is also “an understanding of what makes the learning of specific topics easy or difficult” for specific ages of students.

In a ten year longitudinal study on the growth of an elementary teacher’s science pedagogical content knowledge, Mulholland explained that PCK is “concerned with the translation of subject-matter knowledge for the purposes of teaching.” The researchers used the metaphor of a tree to describe the teacher’s growth over course of the study to show “a complex, developing integration of all that a teacher brings to science classes.” It was found that “while science subject knowledge commences as the major component of science PCK, it is soon overshadowed by general teaching and interactive knowledge…the science knowledge branch remains relatively underdeveloped.” Due to this branch remaining underdeveloped, the teacher involved in the study relied almost entirely upon the science curriculum for science content understanding and teaching. It was true however that “the whole PCK tree [grew] in that [first ten years of teaching] from a small sapling into a thriving, established organism.” Mulholland also concluded that the findings of the study “showed that science ideas are formed early in life, persist rather than be replaced, and are important in later conceptual development.”

Van Driel, Verloop, and de Vos discussed the history of PCK in science teaching and presented case studies of high school chemistry teachers’ PCK. The case studies described teachers’ experiences in the Netherlands within an in-service workshop focusing on the concept of chemical equilibrium. The case studies presented were based on the goals “to improve chemistry teachers’ abilities to recognize specific preconceptions and conceptual difficulties related to chemical equilibrium, and to promote their use of interventions and strategies promoting conceptual change during classroom practice.” It was noted that the findings were limited to certain aspects of equilibrium, but van Driel, Verloop, and de Vos learned how teachers transform their knowledge of chemical equilibrium and how teachers can relate to students understanding of chemical equilibrium. After reviewing much of the literature on PCK, they identified gaps in the PCK literature and suggested needed research studies about teachers’ PCK. One such needed research study would investigate “the ways teachers transform subject-matter knowledge, how they relate their transformations to student understanding, and how they develop these abilities,” thereby adding to the significance of this inquiry.

Smith, in *Examining Pedagogical Content Knowledge*, explained her understandings of PCK in elementary science through her personal experiences as an educator, working with
teachers, pre-service teachers, and researchers. Smith “use[d] PCK to mean knowledge of examples, analogies, and representations drawn from the scientific content of two kinds: substantive knowledge and syntactical knowledge.” Substantive knowledge “refers to concepts, principles, and laws,” for instance atoms, ionic bonds, or enthalpy. Syntactical knowledge refers to “agreements, norms, paradigms, and ways of establishing new knowledge that scientists in areas of science hold as currently acceptable,” like in science where “a hypothesis is never proven correct…if a scientist’s results match his/her predictions, then the hypothesis is supported.” Smith also included “knowledge about how to design [her] teaching and classroom activities so as to facilitate children’s understanding of that scientific topic.”

After explaining the concept of PCK, Smith explained the intricacies of PCK for experienced and pre-service teachers. Elementary teachers focus on creating opportunities for students to discover science and therefore “rarely know about children’s naïve ideas in different areas of science.” When discussing experienced elementary teachers and their substantive knowledge, “it is the firsthand evidence of children’s own strongly held beliefs that makes an impact on elementary teachers” and their PCK. In the elementary grades, listening to student ideas is a focus, therefore, with more experience, teachers hear more ideas and see ways to improve their teaching of those concepts. A main point made by Smith is that “different aspects of teachers’ PCK for teaching particular science topics are not isolated, but rather connected to and interactive with other knowledge.” It was also stressed that there is a critical dependence upon a teachers’ content knowledge in order to grow in PCK.

Inquiry

The teaching paradigm chosen for this research was learning science through inquiry. The importance of inquiry for education in the United States is argued articulately in the National Science Education Standards (NSES). Included in these standards is a section for each grade level entitled “Science As Inquiry Standards.” The rationale for including inquiry as content argues:

Engaging students in inquiry helps students develop understanding of scientific concepts, an appreciation of ‘how we know’ what we know in science, understanding of the nature of science, skills necessary to become independent inquirers about the natural world, [and] the dispositions to use the skills, abilities, and attitudes associated with science.
The NSES also state that “science as inquiry is basic to science education.” Accordingly, science education would be incomplete without inquiry. But what is scientific inquiry? This is a concept with multiple meanings, which are complementary according to Bybee: “…science content that should be understood,…a set of cognitive abilities that students should develop, and…teaching methods that science teachers can use.” The National Research Council states, “Full inquiry involves asking a simple question, completing an investigation, answering the question, and presenting the results to others.” The NSES offer a call for all students in all grade levels to have the “opportunity to use scientific inquiry and develop the ability to think and act in ways associated with inquiry.” The specific standards for grades K-4 state, “As a result of activities in grades K-4, all students should develop abilities necessary to do scientific inquiry and understanding about scientific inquiry.”

Although the construct commonly referred to as inquiry is never explicitly stated, Eleanor Duckworth’s “The Having of Wonderful Ideas” and Other Essays on Teaching and Learning was the starting point for this researcher’s conceptual understanding of inquiry. In that work, Duckworth stated, “The having of wonderful ideas is what I consider the essence of intellectual development.” Duckworth also commented on the diminishing occurrence of what she calls “children’s curiosity and resourcefulness” as children get older. She “thinks part of the answer is that intellectual breakthroughs come to be less and less valued. Either they are dismissed as being trivial or else they are discouraged as being unacceptable.”

Duckworth explained that Piaget saw the importance of conflict in a child’s mind. “It is the child’s own effort to resolve a conflict that takes him or her on to another level.” As with the NSES and inquiry, Duckworth similarly wrote “surprise, puzzlement, struggle, excitement, anticipation, and dawning certainty are the matter of intelligent thought. Even if they do not, on some specific occasion lead to the right answer, in the long run, they are what count.” Mistakes will be made, in fact Duckworth said “making mistakes and correcting them reveal and give rise to a far better grasp of the phenomenon than there would have been if no mistakes were made at all.” Though this approach is very student centered, the role of a teacher in inquiry is quite important. Duckworth said that a teacher should raise questions to push the concepts to the limits with the students. One conflict many teachers have with teaching by inquiry may take more time in order to establish what Duckworth calls learning with “breadth and depth.”
A three-year professional development program was designed by Akerson and Hanuscin\textsuperscript{39} to instruct elementary teachers in teaching the nature of science (NOS) through inquiry. The professional development program consisted of monthly half-day workshops where teachers participated in inquiry lessons and on-site support for teachers. In this study, teachers created their own lesson plans. Data was collected through teacher interviews, a sub-set of student interviews, and responses to the questionnaires VNOS-B (teachers) and VNOS-D (students). The teachers completed the VNOS-B as a pre and post assessment every year of the program, and the students completed the VNOS-D only the second and third years of the program. Other methods of data collection included transcripts, video, and field notes. Akerson and Hanuscin reported of the findings of their research as case studies on three teachers’ experiences in the program and the influence on their students.\textsuperscript{39} Through this study, Akerson and Hanuscin found that “individual support for teachers was a critical element of their social development.”\textsuperscript{39} Akerson and Hanuscin claimed that “the project staff teaching model inquiry lessons while emphasizing elements of NOS seemed to be the most influential component as a trigger for teachers to emphasize NOS in their classrooms.”\textsuperscript{39} They found that the teachers’ science text series offered contradictory views through a “cookbook” approach. Akerson and Hanuscin wrote that their “professional development program would not have been as successful if it were not sustained, nor if it did not have the monthly workshops or individualized support.”\textsuperscript{39}

For this research project, a learning cycle was chosen as the framework to guide inquiry. As part of the National Science Foundation’s sponsored science curriculum development projects to increase early experiences to “authentic science,” The Science Curriculum Improvement Study proposed using the “learning cycle” developed in 1962 by Atkin and Karplus.\textsuperscript{6} The learning cycle is a strong instructional approach benefiting from extensive research\textsuperscript{40} and takes science teaching beyond simply a hands-on, discovery approach.\textsuperscript{41} A type of learning cycle, the 5E learning cycle, consists of five sequential actions: Engage, Explain, Explore, Elaborate and Evaluate.\textsuperscript{9} Bybee\textsuperscript{9} explained the importance of the sequential form: “students construction of knowledge can be assisted by sequences of lessons designed to challenge current conceptions and provide time and opportunities for reconstruction to occur.”
Science in Early Elementary Grades

This research project began with the motivation to increase the amount of time spent on science in a local school district. However, the more important question appears to be: why care about teaching science? *Taking Science to School: Learning and Teaching Science in Grades K-8* provided five responses to the question, “Why Teach Science?”

Science is a significant part of human culture and represents one of the pinnacles of a human thinking capacity.
It provides a laboratory of common experience for development of language, logic, and problem-solving skills in the classroom.
A democracy demands that its citizens make personal and community decisions about issues in which scientific information plays a fundamental role, and they hence need a knowledge of science as well as an understanding of scientific methodology.
For some students it will become a lifelong vocation or avocation.
The nation is dependent on the technical and scientific abilities of its citizens for its economic competitiveness and national needs.

These are all very valid points, but the question still remains: why not delay a focus in science teaching until students get older?

Hellden conducted a longitudinal study that looked at the personal context and continuity of twenty-three students on their understanding of ecological processes, where each student was interviewed eleven times from age nine to fifteen. During interviews, students listened to past interviews to remind them of their previous conceptions. For instance, when fifteen, students listened to what they said during interviews when they were eleven and listened to themselves at fifteen when nineteen. Hellden found that “early experiences of different phenomena seem to play an important role in the development of many children’s conceptual understanding.” He also called for introducing scientific concepts at an earlier age.

As discussed previously, The National Research Council developed and instituted the *National Science Education Standards*. There are eight content specific standards, which include unifying concepts and processes in science, science as inquiry, physical science, life science, earth and space science, science and technology, science in personal and social perspective, and history and nature of science. Due to the pressures teachers in the elementary grades feel to focus their teaching on language arts and math, science became a subject of less importance within their curricula. If science is being marginalized already, how much more are the
specific science standards that are viewed as difficult by teachers not being taught? For the current research study, the focus was on one of these areas, the physical sciences, and support was provided to the teachers as they taught physical science in their classrooms.

Albert Einstein said, “The goal of education is to produce independently thinking and acting individuals.” The use of scientific inquiry as a teaching method provides students the opportunity to thinking independently. The authors of Taking Science to School: Learning and Teaching Science in Grades K-8 called for the following:

The science curriculum in the elementary grades [is to] be designed for all students to develop critical basic knowledge and basic skills, interests, and habits of mind that will lead to productive efforts to learn and understand the subject more deeply in later grades. If this is done well, then all five of the reasons to teach science will be well served. (p. 34)

This curriculum focus will prepare students who will become scientists and also prepare students to be educated decision makers concerning scientific matters.

**Conclusion**

The literature concerning the research questions is extensive, but the combination of the research questions has not been studied previously. The methods chosen to study the research questions are discussed in Chapter 3.
Chapter 3: Design of Inquiry and Methodology

Introduction
This chapter describes the structure and design of the study to explore kindergarten and first grade teachers’ knowledge and experiences teaching science through inquiry. Emphasis is placed on the methods employed for gathering and analyzing the data.

Research Questions
The inquiry was guided by the following research questions, developed through the influence of Novak’s theory of Human Constructivism. How does teaching science through inquiry affect teachers’:

- knowledge about the particulate nature of matter?
- self-efficacy about teaching science?
- pedagogical content knowledge about teaching science through inquiry?

The nature of the research topics and the desire to focus on the individual teacher’s experiences while implementing the 5E learning cycles dictated the use of a qualitative approach, specifically the use of case studies.

Qualitative Research
Prior to the twentieth century, Auguste Comte’s positivistic approach was the prevalent method for research, focusing on explanation, prediction, and proof using positive or observable facts, which is in essence, the scientific method. However, the positivist perspective stands in opposition to the constructivist perspective discussed in the previous chapter. Lincoln and Guba explain that events, people, and objects are observable and tangible, but “the meanings and wholeness derived from or ascribed to these tangible phenomena in order to make sense of them, organize them, or reorganize a belief system, however, are constructed realities” (p. 84). Therefore, an alternative paradigm exists in interpretivism, an approach to research which focuses on understanding the meaning of events as they relate to the individuals being studied.

Because knowledge is an individualistic construct, multiple realities exist which can only be understood as related because they form an interconnected whole. Therefore, an interdependence exists between the knower and the known. This process of knowledge
construction is informed by the knower’s values, which “mediate and shape what is understood.”

Events that take place within the knower’s reality are not individual but are related to each other. The relationship between these events is discoverable. The interpretivist perspective focuses less on the causality of these events and more on their multi-directional relationship. Any understandings gained by such a perspective are contextually-embedded and have limited generalizability. Finally, this perspective seeks to discover patterns, which emerge from the data collected.

Research in chemistry education explores the practices of teaching and learning chemistry, and this is dissimilar to traditional bench chemistry where the aim is to study matter and its properties, composition, and structure. Due to the disparate research ends, the research paradigm required for each is different. The traditional scientific method employs research questions where one variable is tested and all others are controlled; however, some research questions in chemistry education “do not suggest an experimental design where one variable can be manipulated while all others are held constant in order to confirm a hypothesis which defines the relationship between two such variables.” This was true for this research with the elementary teacher’s experience because the research questions did not dictate the scientific method. Rather, the research questions dictate the interpretivist paradigm. The discovery of the multi-directional relationships between events within the teachers’ experiences was sought. This research was embedded in the context of the school district and could not be generalized widely because no two situations involving humans are reproducible.

The Case Study Approach

Creswell cites five approaches to qualitative research: narrative research, phenomenology, grounded theory, ethnography, and case study. For this inquiry, the case study approach was employed. As in any research study, the object to be studied must also be chosen in qualitative research. In case studies, the individual case is the object to be studied. A case is a bounded system with integrated working parts. The case is specific or singular, however, it does have complexities. Stake explains that holistic case study examines these complexities. “The more the object is a specific, unique, bounded system, the greater the usefulness of the research. This specific and bounded system gives rise to the environment for indwelling by the researcher. Indwelling is to “exist as an interactive spirit, force or principle – to exist within an
activating spirit, force or principle.” Indwelling is the means by which the complexities of the case are found. Therefore, “the posture of indwelling [is] central to our understanding of qualitative research.” “The data collection in case study research is typically extensive, drawing on multiple sources of information.” Lincoln and Guba describe case studies this way:

[Case study reporting] is more adapted to a description of the multiple realities encountered at any given site: because it is adaptable to demonstrating the investigator’s interaction with the site…because it provides the basis for both individual “naturalistic generalizations” and transferability to other sites (thick description); because it is suited to demonstrating the variety of mutually shaping influences present. (p. 42)

Creswell explains the characteristics of qualitative research, which include the natural setting, the researcher as the key instrument, multiple sources of data collected, inductive data analysis, focus on participant meanings, emergent design, theoretical lens, interpretive inquiry, and a holistic account. These characteristics will be expounded upon throughout this chapter as they pertain to this research.

In this research study, the chosen cases were elementary teachers experiences with inquiry teaching and were specific, unique, and bounded. This research was specific and bounded by the local school district. The cases were unique because the teachers had wide levels of experiences in teaching kindergarten and first grade and had diverse background experiences in teaching inquiry.

**The Natural Setting**

Denzin and Lincoln state that “qualitative researchers study things in their natural settings, attempting to make sense of, or interpret, phenomena in terms of the meanings people bring to them.” The school district where the inquiry took place is a rural district located in southwest Ohio. The district has a mission statement that reads, “To ensure that all students succeed by providing quality program and instruction, engaging our stakeholders and maintaining fiscal responsibility.” The district has three elementary schools, which eventually combine into one middle school and one high school. Kindergarten through second grade teachers in all three elementary schools were invited to participate. One of the elementary schools became the focus of the inquiry due to the teachers who volunteered to participate. This
school has students in pre-kindergarten through fifth grade. There are four sections of both kindergarten and first grade in this particular building. The Ohio Department of Education rated this elementary school Excellent for Academic Achievement for the 2006-2007 school year.

**Researcher as Key Instrument**

In qualitative research, it is critical to recognize that the researcher plays a central role in the collection and analysis of data. This is quite different from quantitative research because as Maykut and Morehouse explain, “researchers in the traditional orientation look to reliable and valid non-human instruments of data collection and statistical analysis, while the qualitative researcher looks to the human as instrument for the collection and analysis of data.” Given the pivotal part the researcher plays in building mutual understanding with the subjects of this inquiry, it is the responsibility of this researcher to provide the reader with an account of her life experiences that have shaped this work:

Since seventh grade, I have known I wanted to be an educator, but I did not know for sure which content area I would choose as my focus. After taking chemistry and physics my junior and senior year of high school, respectively, I knew I wanted to be a high school chemistry and physics teacher. I came to Miami University in 2003 as an undergraduate with a major in physical science education. I took many courses in chemistry and physics, as well as many courses in the School of Education and Allied Professions.

Junior year was a very influential year on my perspectives of education. At Miami, the junior year is the time for education majors to take their methods courses. Students are grouped together to take courses on teaching their content area. I had the privilege of having Dr. Ann Haley Mackenzie as my science methods professor, from whom I learned an incredible amount about teaching science. I began to make conscious decisions about who I was going to be as an educator. The major theme of the year was the teaching method of inquiry. It was during these courses that I was first introduced to the 5E learning cycle as a way of teaching and learning science through inquiry. Through participation in inquiry activities, I realized how inquiry allows students to learn in a meaningful way.

It was also junior year when I began working with Dr. Stacey Lowery Bretz as an undergraduate researcher in chemistry education. I grew immensely in my knowledge and understanding of research and education through this experience. In the spring of that school year, I began working with the project through the Miami University Partnership Office to incorporate science and literacy in kindergarten, first, and second grades. It was during this time that I really began thinking about the importance of quality science education in the first years of formal schooling for students. The opportunity arose to continue this study as a graduate student, and graduate school experience has contributed immensely to my knowledge and understanding of chemistry education. As a future science educator, I have the desire to develop a partnership with
elementary teachers to create a science mentorship program between high school and elementary students.

Because of the experiences of the science methods courses and the research, I believe in the 5E learning cycles. I played a large role, along with Dr. Stacey Lowery Bretz, Dr. Nazan Uladag Bautista, Beth Marie Motter, and the school’s science curriculum director in the creation of the 5E learning cycles used in this inquiry. Finally, through my experiences with this research and graduate classes in chemistry education, I have grown to philosophically agree with the concept of meaningful learning and the theoretical framework of Human Constructivism.

**Recruitment of Research Subjects**

In order to conduct this research, the researchers adhered to federal law and rules of Miami University to submit a research proposal to the Institutional Review Board (IRB). The development of materials for the 5E learning cycles had already begun under the IRB 05-184, “Science Partnership Research Associates Program.” Teacher participation in all aspects of the research was voluntary. IRB approval was granted for the case studies for this project under IRB 06-262, “How Does Children’s Literature Impact K-2 Teachers’ Views of Teaching Science Through Inquiry?” There was no benefit or penalty for teachers with regards to their access to the 5E learning cycles. Only those teachers who expressed interest in the project were contacted for participation. Upon approval from the IRB, the research began in spring of 2007.

The science curriculum coordinator gave the researchers permission to invite the teachers of the district to participate in the project. The K-2 teachers had previous knowledge of the 5E learning cycles as the researchers had presented a learning cycle to the teachers previously during in-service professional development. Participants were required to read and sign an informed consent form prior to their participation in any interviews, assessments, or reflective journals. An invitation to participate in the research was given to all K-2 teachers in the district at in-service meetings for the teachers. Each grade had separate meetings on three different days. It was the researcher’s intent to employ purposeful sampling. Three teachers who volunteered to participate were to be selected in order to diversify years of teaching experience, prior experience with inquiry, race, and gender to the extent afforded by those teachers who responded. However, the three teachers who responded and signed the consent form were one kindergarten teacher and two first grade teachers. Each of these three teachers taught in the one elementary building as previously described.
**Data Collection**

Given the framing of this research study by Novak’s Human Constructivism\(^1\), the methodologically sound choice was made to qualitatively collect data in and across the three domains of learning: cognitive (think), affective (feel), and psychomotor (act). A Venn diagram is shown in Figure 3 to illustrate how these three domains come together to create meaningful learning. Specifically, the cognitive domain was studied through an interview on the knowledge of the particulate nature of matter (PNM). The affective domain was studied through a questionnaire on self-efficacy called the Science Teaching Efficacy Beliefs Instrument (STEBI).\(^43\) The psychomotor domain was studied through the teachers’ implementation of 5E learning cycles into their classrooms. The intersection of the cognitive and psychomotor domains was studied through the knowledge of teaching science through inquiry, as assessed by the Pedagogy of Science Inquiry Teaching Test (POSIT).\(^51\) Finally, the intersection of the cognitive and affective domains, as well as the intersection of the affective and psychomotor domains, was studied through reflective journals completed by the teachers during and after the learning cycles.

*Figure 3. Representation of the merging of meaningful learning and this research project.*
Development of 5E Learning Cycles

Before the research about teachers could begin, the 5E learning cycles needed to be created. Based on the expressed desire of the teachers in the district to incorporate science with literacy, the materials development began for the learning cycles in spring of 2006. The researchers selected science trade books from a list provided by Ansberry and Morgan,\textsuperscript{52} recent authors of a book on 5E learning cycles for grades three through six. After reading each trade book, the researchers developed a matrix (Appendix C) linking children’s literature to the indicators from Ohio’s Academic Content Standards K-12 Science\textsuperscript{4} for kindergarten, first, and second grade (Appendix B). In May and June 2006, the researchers prepared and presented a sample 5E learning cycle for the teachers at in-service professional development meetings. Explanations on the 5E learning cycle from Picture-Perfect Science Lessons: Using Children’s Books to Guide Inquiry, Grades 3-6\textsuperscript{10} were used to help introduce this instructional model.

Kindergarten through second grade teachers throughout the district selected the trade books they wanted to have activities developed for use in their classrooms. The researchers then began to create 5E learning cycles incorporating the reading of the science trade book and its corresponding science content standard. Once a 5E learning cycle was completed, a kit with all hands-on supplies was made available to all K-2 teachers in the school district. Specifically, a kit was supplied to each of the three schools for the teachers at that school to share. A completed 5E learning cycle for kindergarten is shown in Appendix D.

The collection of learning cycles was continually supplemented and revised throughout the project. In May 2007, this researcher met with Dr. Ann Haley Mackenzie to discuss the strengths and weaknesses of the 5E learning cycles. Her recommendation, to ensure that the students were creating definitions of the concepts during the Explain portion of the learning cycle, was immediately and continually implemented after this meeting. The science curriculum director was also instrumental in the revision process. The science curriculum director and the researchers met approximately once a week during the fall 2007 semester. He worked along with the researchers to make the appearance of the learning cycles friendlier to both teachers and students in the elementary grades, including fonts, font sizes, and wording of instructions and questions. The science curriculum director also helped to make revisions to the activities themselves to ensure the specific indicators were met. Finally, another source of input on the 5Es were the teachers. At in-service meetings, teachers gave feedback on learning cycles after
participating in them. Also, the three teachers implementing the learning cycles for this project provided feedback to the researchers throughout the year.

Data Collection - Spring 2007

Through the process described previously within this chapter, three teachers volunteered in spring of 2007 to participate in the case studies. After giving informed consent (Appendix E), each teacher was asked to attend two individual meetings prior to their experience implementing a 5E learning cycle into their classroom. The first meeting involved the teacher responding to semi-structured interview46 using the Interview Guide (Appendix F), demographic questionnaire (Appendix G), PNM interview (Appendix H), the STEBI-A43 (Appendix I), and POSITT (Appendix J). The interviews were recorded using a digital voice recorder and later transcribed. The second individual meeting specifically discussed the 5E learning cycle. The teachers then implemented the selected 5E learning cycle into their classroom. During this experience, teachers were asked to journal. These journal prompts are listed in Appendix K.

Particulate Nature of Matter Interview

A five question semi-structured interview46 was adapted from sources on misconception research14 and the Chemical Concepts Inventory.53 The five questions probed concepts relating to the national and state standards for science in K-2 (Appendices A and B). The five questions addressed the following concepts: particulate space, condensation, conservation of mass, water as a vapor, and gas particle behavior. From the extensive literature on misconceptions research, concepts were chosen according to the standards and developed into interview questions. Questions from the Chemical Concepts Inventory53 were modified from multiple-choice questions to create free response questions, so as to permit the researcher to gain more detailed information about the teachers’ knowledge.

Science Teaching Efficacy Beliefs Instrument

In order to assess the teachers’ learning within the affective domain, the researchers desired to know the level of efficacy with regard to science of the elementary teachers in this case study. The Science Teaching Efficacy Belief Instrument43 (STEBI-A) for in-service teachers was chosen to aid in determining the teacher efficacy of each teacher. This instrument
has been found to be both valid and reliable in previous studies.\textsuperscript{26, 43} This instrument contains two scales: Personal Science Teaching Belief Scale (self-efficacy dimension) and Science Teaching Outcome Expectancy Scale (outcome expectancy dimension).\textsuperscript{26} The STEBI contains 25 statements with a Likert scale (strongly agree, agree, uncertain, disagree, strongly disagree) with 13 positively written and 12 negatively written statements shared between the two scales. Efficacy studied through the STEBI, in conjunction with interviews, journals, and meetings, with teachers allowed for the efficacy construct to be explored both quantitatively and qualitatively for individual teachers.

\textit{Pedagogy of Science Inquiry Teaching Test}

The Pedagogy of Science Inquiry Teaching Test (POSITT) is currently under development by researchers at Western Michigan University.\textsuperscript{51} The goal of the researchers at WMU is to develop and validate the POSITT for assessing K-12 teachers’ pedagogical knowledge of inquiry science teaching, as they have found a gap both in the research and in the assessment tools for this construct. The instrument contains “case-based teaching vignettes.” Ultimately they plan to develop tests for teachers in three grade groups containing about 30 questions per group. They plan to write each of these questions in three different formats: multiple-choice, ranked response, and short answer constructed responses. Each of the questions will be piloted, analyzed, and revised.

Given the absence of validated, reliable assessment tools for pedagogy in inquiry science teaching, six of the vignettes in multiple-choice format were shared with the researchers to pilot in this project. The researcher created a second part to each of the six questions, by asking the teachers to respond to the question: why did you choose this response over the other possible responses? This additional question allowed for the teachers to elaborate on their answers and more fully explain their understanding of inquiry to the researcher. The use of such “two-tiered” conceptual questions has precedence within the literature.\textsuperscript{54, 55}

\textit{Reflective Journals}

The journals provided an opportunity for teachers to recall and reflect upon their classroom experiences with the 5E learning cycles. The teachers were asked to journal everyday during the implementation of a 5E learning cycle and complete one post-journal to reflect on
their experience. The journals gave the teachers a way to communicate with the researcher through writing. The journals were sent to the researchers via email or provided in written form and picked up at the school. Written journals were transcribed.

Data Collection - Fall 2007

The same three teachers were asked to again implement a 5E cycle developed by the researchers into their classroom, participate in meetings, and write journals during and post-implementation of the learning cycle. Given the emergent design of the study, the researchers modified the journal questions for the second 5E learning cycle to reflect the fact that this was not the teachers’ first learning cycle experience. The new questions are listed in Appendix L. The book and activities of this second 5E learning cycle were different than that of the spring semester due to the individual teacher’s decision to teach certain topics in the curriculum at these specific points during the year. At the end of the fall 2007 semester, the three teachers were asked to participate in a second interview, the PNM interview, and complete the STEBI and POSITT. This second interview used a different interview guide than the first, as the researcher had new questions after the teachers’ additional experiences with inquiry. The Second Interview Guide is included in Appendix M.

Data Analysis

Analysis of the gathered research data was conducted simultaneously with data collection and further analyzed after all data was collected. The process of qualitative analysis was based on case study analysis. The researchers employed data reduction into emergent themes and interpretation through the organization of data into concept maps, graphs, and tables. The multiple sources of data allowed for the triangulation of data.\textsuperscript{45, 47, 56}

The case study analysis was completed as holistic analysis\textsuperscript{47}, in which the entire case was analyzed for each teacher. First, the individual case was presented in detailed description within the context of the case and themes were then analyzed within each case (Chapters 4, 5, and 6); and finally, cross-case analysis\textsuperscript{47} was performed, where the themes were analyzed across the cases including assertions of the meaning of the cases (Chapter 7).

Concept maps were used in the analysis of the PNM interview and POSITT. Concept maps are a graphical tool for organizing and representing knowledge\textsuperscript{57} and were developed with
the purpose of representing changes in knowledge over a period of time. Novak’s work in Human Constructivism resulted in the development of concept maps. Bretz describes concept maps as a “two-dimensional representation of the three-dimensional knowledge network within the…mind.” Concept maps were used to analyze the semi-structured interviews conducted in this research, but also to communicate findings from this qualitative study. The computer software CmapTools aided in the process of creating and analyzing the concept maps.

PNM Interview

After the interviews were transcribed, the researchers formulated concept maps of each teacher’s explanations of individual questions within the interview. For the particulate nature of matter interview, several lenses were brought to the analysis. The teachers’ responses were analyzed as correct or incorrect, focusing on Harrison and Treagust’s descriptions of common misconceptions and the distracters in Mulford’s original multiple-choice questions (Appendix N). Another level of analysis was changes in conceptions between the pre and post-interviews, be they increased or regressed understandings. Also, due to previous findings by Williamson, Huffman, and Peck about the use of the particulate theory within responses to questions, the use of particulate understanding within answers was analyzed. Finally, the theme of teachers’ mention of uncertainty in their explanations was analyzed.

Science Teaching Efficacy Beliefs Instrument

The STEBI was scored using the method described by Enochs and Riggs. Each question has a maximum score of five and a minimum score of one. All negatively worded questions were re-coded in the process of data analysis and presented this way in all graphs within the following chapters (see Appendix O). The Personal Science Teaching Belief Scale (PSTBS) contains 12 questions with a maximum score of 60 and the Science Teaching Outcome Expectancy Scale (STOES) contains 13 questions with a maximum score of 65. Therefore, the STEBI has a maximum composite score of 125 and minimum composite score of 25. In analyzing the results, the researchers considered the teachers’ overall STEBI scores and their scores on the two scales.
The POSITT was analyzed for the correctness of responses based on the answers shared by the group at WMU and the literature\(^{51}\) (Appendix P). The explanations provided by the teachers for their multiple-choice responses were analyzed using concept maps.

**Trustworthiness of the Inquiry**

Whereas the traditional research paradigm uses internal and external validity, reliability, and objectivity as methods for developing trustworthiness of the research, the interpretivist paradigm establishes trustworthiness through the analog constructs of credibility, transferability, dependability, and confirmability.\(^{45}\) The research described herein is *credible* because it was a year in length in order to learn the context of the school and build trust between the researcher and the three teachers.\(^{45}\) Credibility was also established given the triangulation\(^{45}\) of the multiple data sources described previously in this chapter. In case studies, triangulation of multiple data sources is employed to strive for the story being told as true to actual as possible.\(^{48}\) Member checks were employed during each interview, adding to the credibility of this research. Member checks are a way to check the intentions of a respondent’s statements and allows for the respondent to make any corrections in their answers.\(^ {45}\) The characteristic of trustworthiness called transferability requires the researcher to establish a thick description of both the time and context in which the study took place, so that another researcher can make a decision regarding the extent to which these findings are indeed transferable.\(^{45}\) However, case studies are unique, so the findings of these case studies have limited generalizability. The cases are a unique interpretation of the events within the school as the teachers incorporated science and literacy through the 5E learning cycles. Furthermore, “damage occurs when commitment to generalize or create theory runs so strong that the researcher’s attention is drawn away from features important for understanding the case.”\(^ {44}\) Dependability is the analog of reliability, however it is known that in the traditional research paradigm, reliability cannot be had without validity.\(^ {45}\) This research is *credible* and therefore also *dependable*. The final characteristic of trustworthiness is confirmability.\(^{45}\) The researcher as the human instrument described previously does not allow for objectivity. However, the triangulation of multiple data sources during this research, along with the theory of research presented, ensure for both the dependability and confirmability of this study.\(^ {45}\)
Conclusion

This chapter described the methods for both qualitative and quantitative data collection and analysis used within this research study. The next three chapters present the data collected and analyzed from the study regarding each of the three teachers’ experiences with teaching science through inquiry.
Chapter 4: Findings and Analysis of Aubrey’s Case

Introduction

In this chapter, the findings of the case study are presented for Aubrey followed by the analysis of her individual case. The findings offer a description of Aubrey and her responses to interview questions, descriptions of the 5E learning cycles used in her classroom, her journal entries after the 5E learning cycles, her responses to the PNM interview, STEBI results, and finally POSITT results. Concept maps are used throughout this chapter to represent Aubrey’s understandings of the PNM and the POSITT.

Description of Aubrey and her Interviews

As a teacher of 13 years, Aubrey had been teaching kindergarten in the district for six years. She was 36 years old at the start of the study and had a Bachelor’s Degree from Miami University. For the first five years of her career, Aubrey was a Title I kindergarten teacher where she taught only language arts. Then she transitioned to a half-day kindergarten position. Of the four kindergarten teachers in the building at the time was of the project, she was the only teacher who taught half-day kindergarten; the other three teachers taught kindergarten for the full school day. Aubrey liked this schedule because she has two children at home. With only a half day of school and having to teach three “specials” like music and gym classes throughout the week, time was a large factor for Aubrey. When choosing to participate in this project, Aubrey explained she was willing to take part in the interviews and assessments during the spring 2007 but was not able to start implementing the 5E learning cycles until fall 2007.

Aubrey initially felt that language arts was the subject of primary importance for her classroom. She was comfortable teaching language arts, and she believed it to be imperative for the kindergarten students as they develop their reading skills. Because of these beliefs, Aubrey did not spend much time on science, especially the physical science standards. Further, she explained she was not very comfortable teaching these standards. Although she enjoyed science experiments, the extensive time needed for set-up was a drawback. This was not to say, however, that she believed science was unimportant. Due to the lack of time she taught science, Aubrey admitted that she even “felt guilty” about not spending more classroom time on science. She shared that her goal for the 2007-2008 school year was to incorporate more science into her
classroom. In fact, she chose to participate in this research project specifically to teach more science. In December after her two 5E learning cycles on the physical sciences, Aubrey said these standards are the hardest for her to work into the curriculum: “[t]he materials, how things move…I just don’t do those very often. I mean we do stuff like that, but I am not talking about it scientifically.” She said her “excuse” for this is that “in a half day, it has not been a priority…Every principal I have ever had has said you need to teach language arts and math.” Aubrey also explained after her second 5E learning cycle that she had never taught that standard prior to that experience. At the end of the learning cycles, Aubrey said she was trying to incorporate science, specifically the “unfamiliar” physical science standards, into her language arts lessons.

When asked to reflect upon the word “inquiry” in April 2007, Aubrey believed inquiry to be a mostly positive concept; however, it could be hard at times to get the students to learn through inquiry. Her prior experiences with inquiry were in teaching math. Her math inquiry experience increased further during summer 2007 when Aubrey attended a math workshop at Miami University with a focus on inquiry. After attending this workshop, she expressed that, “[i]t is easier to be open-ended now.” Aubrey implemented the 5E learning cycles into her classroom in fall 2007. After these experiences, she again reflected on inquiry:

[Inquiry] is positive to me and I think…inquiry is really letting them discover…which is really good, but really hard to do…You can let them discover so much but no matter how…many times I let some child[ren] discover…they’re not going to get it…So I think you have to balance it out. You have to let them discover, but there’s also some things you have to show them or tell them. They’re not going to be able to discover everything on their own.

Aubrey continued describing the concept of inquiry teaching and where she felt she was at the end of the project. Aubrey explained inquiry “went really well…[when] done after [she] had introduced [the concept]…but it was much harder for...students and for [her when they] hadn’t done anything else with that yet.” When she discussed guidance in inquiry, she said, “...it was really hard for me to guide them without telling them.” She also said she “wouldn’t say [she] can always put it into practice well..[she is] in the learning stages of putting it into the practice.” She expressed a desire to keep practicing and even contribute more 5E learning cycles to the collection available.
5E Learning Cycles

During the project, Aubrey implemented two 5E learning cycles, “Sorting” and “Materials Classification.” “Sorting” is a learning cycle focused on the Ohio kindergarten physical science indicator three, which states “Describe and sort objects by one or more properties (e.g., size, color and shape).” It uses of the book *Sorting*\(^1\) within the Explain portion of the 5E learning cycle. Aubrey spread this learning cycle over two days. “Materials Classification” was a learning cycle pertaining to Ohio’s kindergarten physical science indicator two, which states “Examine and describe objects according to the materials that make up the object (e.g., wood, metal, plastic and cloth).” During the Elaborate section of the learning cycle, the science trade book *The Great Trash Bash*\(^2\) was read. Aubrey spent one day on this learning cycle.

Reflective Journals

As Aubrey implemented her first 5E learning cycle entitled “Sorting” into her classroom, she described her experiences: “It was a lot of fun doing the sorting activity with my class.” She said the students were “very excited about all the different steps” included within the learning cycle. She felt it was a good choice to complete the learning cycle over two days, because her students were “sorted out” after the first part, because they had done so much sorting that day. She was most surprised by her students’ ease with the actual sorting, but that she “had to really draw it out of them to come up with the word ‘sorting.’” She said the students used words such as patterns, organizing, matching, and putting away.

Aubrey then took time to write a journal reflecting on her experience. She felt that the strengths of the 5E model included keeping the students on task and “very involved in their own learning.” She explained that for her and her class, the elaboration portion was the most difficult because both her and her students were “not used to having to explain their thinking.” She did express she saw the Elaborate as “a very strong part of the lesson.” The group work was seen as good practice for the students; however, when it came to the evaluation, it was quite difficult to assess which student was actually doing the sorting of the sponges. Finally, Aubrey expressed her “love” for teaching all subject areas through the use of literature.

Aubrey also kept a journal for her second learning cycle experience, and through this, she thought that in comparison to “Sorting,” the concepts within “Materials Classification” were
much more difficult for the students to grasp. She wrote that the students had difficulty
describing the objects by the materials in which they were made, but instead described their
properties, such as hard. The students also had a hard time coming up with definitions for the
materials.

In her reflection about the “Materials Classification” learning cycle, Aubrey expressed
less confidence in teaching with the 5E model, even though this was her second 5E learning
cycle. In comparison to the “Sorting” learning cycle where her class had focused on sorting for a
while before the learning cycle, her students had no prior experience with “materials.” Aubrey
conveyed her desire to elongate the learning cycle and evaluate a week or two later, rather than
the same day. Aubrey “[thought] the 5E model is a great structure for inquiry.” She did express
that it was possible to “use this model but still ‘teach’ it if they ask the wrong questions or not let
the students discover on their own.” Aubrey explained that this experience required her to think
“much deeper about science concepts…to make sure [she] was leading the students the correct
way.” This learning cycle left her with the desire to go further with each of these materials to
ensure her students grasped a deep understanding of the concepts. Finally, she wrote, “After
doing this experience, I realize (again) how fun teaching science can be. It is just difficult
getting all the materials ready, so having these kits is very helpful.”

**Particulate Nature of Matter Interview**

Aubrey participated in the PNM interview in June 2007 and again in December 2007
after implementing two 5E learning cycles. Concept maps for each of Aubrey’s explanations are
shown in conjunction with discussion of her conceptions. Within these concept maps, the red
d lines indicate explanations Aubrey provided in the pre-interview, the blue lines indicate her
explanations in the post-interview, and the black lines indicate explanations that she offered in
both the pre and post-interviews. A blue or red asterisk signifies the teacher’s final answer to the
question within that particular interview if they had discussed other options in addition to their
final answer. These conventions will be used throughout the presentation of all three cases.

The concept map in Figure 4 shows Aubrey’s understanding of the first question on space
and orientation of matter at the particle level. Aubrey expressed in the pre-interview that there is
always some space in a solid. In the post-interview, she explained that, “[m]atter is made up of
individual particles.” She related the distance between particles to density: the denser the
material, the closer together the particles will be. Using water as an example to make her point, she explained that the particles in frozen water are closer together, liquid water further apart, and as a gas, very far apart.

For the second question on the formation of water on the outside of a glass of cold milk, Aubrey’s conceptions are mapped out in Figure 5. She explained that the water on the outside of the glass was called condensation. In the pre-interview, she said the condensation comes from the air, where it is always found. She said she did not know “the scientific reasoning” for how the condensation got there, but felt that it was from “the cold.” In the post-interview, she elaborated on her pre-interview response by saying that it was the cold that “attracts” the water to form the condensation on the outside of the glass.

For question three on the mass of a solution of 1 pound of salt dissolved in 20 pounds of water, Aubrey believed that 21 pounds was the “obvious” correct answer, which she expressed during both interviews. However, in the pre-interview, she veered from what she had called
obvious and chose her final answer between 20 and 21 pounds with the reasoning that matter has changed form since the water dissolved the salt but was still there. In the post-interview, she first explained the mass was definitely greater than 20 pounds due to weight being added. She chose 21 pounds as her final answer for the conservation of mass. These conceptions are shown in the concept map in Figure 6.

Aubrey explained during the pre-interview for question four that in comparison to liquid water, evaporated water would spread out within the magnified view, but expressed an uncertainty whether it “comes apart.” She concluded that it does not “come apart.” During the post-interview, Aubrey explained that the molecules evaporate, separating into the gas forms of hydrogen and oxygen. Her drawing also showed hydrogen and oxygen as monatomic. The drawing did show that the oxygen and hydrogen were more spread out within the magnified view. These conceptions are shown in Figure 7.

Finally for question five when a liquid is heated to a gas, Aubrey chose option A for her answer in both the pre and post-interviews. Option A depicts the particles in gas form spreading.
out and remaining the same size. In the pre-interview, she explained that the particles in a gas spread out compared to in a liquid because they are moving faster, but do not increase in size. In the post-interview, option A was explained as “they” take up more space because they move faster, but again, do not increase in size. These conceptions are mapped in Figure 8.

Use of Particulate Theory in Explanations

The five interview questions within the PNM interview are written on different levels of matter and therefore, cue responses on the same level. Questions one, four, and five are written at the particulate level, whereas questions two and three are written on the macroscopic level. Aubrey’s interview was analyzed for her understanding of the particulate nature of matter to construct her answers. As can be seen by the findings presented in Table 1, Aubrey invoked particle explanations during the pre-interview in only question five. She described the gas “particles” as they spread out and move faster than particles as liquid without increasing in size.
In the post-interview, she used the particulate theory to answer both questions one and four, but no longer in question five. In question one, she referred to “individual particles” and their relative space in different phases of water. In question four, she referred to “molecules” when asking what she was supposed to do: “So I am supposed to show what it would look like when it evaporates…like what the molecules would look like?” She did not use the terms molecules or particles in any of her other explanations during the post-interview.

**Table 1. Aubrey’s use of the particulate theory.**

<table>
<thead>
<tr>
<th>Question</th>
<th>Pre-Interview</th>
<th>Post-Interview</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>√</td>
</tr>
</tbody>
</table>

**Uncertainty with PNM as shown in Explanations**

Aubrey expressed uncertainty in her answers at times throughout her interviews, as shown in Table 2.

**Table 2. Uncertainty in the PNM Explanations for Aubrey.**

<table>
<thead>
<tr>
<th>Question</th>
<th>Pre-Interview</th>
<th>Post-Interview</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Aubrey had several noteworthy instances of her uncertainty. Aubrey took a pause during her pre-interview explanation of question one regarding the space and orientation of particles and expressed, “I hope I am recalling correctly from when I was in school.” When answering the post-interview question three about mass of the salt water solution, she said, “That would be my guess…but it seems like that would be wrong because that seems really obvious. My guess would be 21.” Another occurrence was the fourth question about particles in evaporated water in the post-interview where Aubrey was trying to decide between the water molecules staying intact or separating. Aubrey said, “See I don’t know which one is right, but we’re going to go with [the separation of oxygen and hydrogen].”
Science Teaching Efficacy Beliefs Instrument

Aubrey provided responses to the Science Teaching Efficacy Beliefs Instrument (Appendix I) as a pre-test in April 2007. After using the two 5E learning cycles in her classroom, she provided her responses to the STEBI again as a post-test in December 2007. Her scores are shown in Table 3 for the two scales, the Personal Science Teaching Belief Scale (PSTEBS) and the Science Teaching Outcome Expectancy Scale (STEOS), and the combined overall score.

The PSTEBS assesses the self-efficacy dimension and has a maximum score of 65 and minimum score of 13. The STOES measures the outcome expectancy dimension and has a maximum score of 60 and a minimum score of 12. Though the STEBI contains questions that are worded positively and negatively, the STEBI results presented with the negatively worded questions recoded.

Table 3. STEBI results for Aubrey.

<table>
<thead>
<tr>
<th></th>
<th>PSTEBS</th>
<th>STOES</th>
<th>Overall Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Test</td>
<td>45</td>
<td>46</td>
<td>91</td>
</tr>
<tr>
<td>Post-Test</td>
<td>43</td>
<td>47</td>
<td>90</td>
</tr>
</tbody>
</table>

Aubrey’s overall score decreased by 1 point between the pre-test and the post-test, due to the a decrease of 2 in the PSTEBS and a marginal increase of 1 in her STOES score. Figure 9 and Figure 10 show Aubrey’s responses to the individual questions of the PSTEBS and STOES, respectively. Though the overall score of the PSTEBS did not change, nine out of the fifteen responses provided by Aubrey changed between the pre- and post-tests. Aubrey’s responses also varied between the pre- and post-tests for the STOES as shown in Figure 10. Aubrey responded with scores of 5 to questions fourteen and fifteen in the pre-test, but did not respond as such in the post-test. Aubrey’s score for this scale still increased by one point overall from pre- to post-test. Changes in Aubrey’s responses across the two STEBI scales can be seen more clearly in Figure 11 and Figure 12. These figures show graphs of the difference between the pre-test score and the post-test score for each question.
Figure 9. Pre- and Post-PSTEBS Individual Question Scores for Aubrey.

Figure 10. Pre- and Post-STOES Individual Question Scores for Aubrey.
Figure 11. Difference in the pre- and post-PSTEBS for Aubrey.

Figure 12. Difference in the pre- and post-STOES for Aubrey.
Pedagogy of Science Inquiry Teaching Test

Aubrey first completed the Pedagogy of Science Inquiry Teaching Test (Appendix J) in June 2007 and again in December 2007 after she had implemented the two 5E learning cycles. Her answers to the multiple-choice portion of each vignette are shown in Table 4, with the score allotted that answer (see Appendix P). Note that with the exception of vignette six, Aubrey’s answers remained unchanged from the pre- to post-test. However, her responses to the second part of each vignette, which asks “why did you choose this response over the other possible responses?” did change. Concept maps (Figures 13 – 18) were created to represent these open-ended responses.

Table 4. POSITT multiple-choice responses for Aubrey.

<table>
<thead>
<tr>
<th>Vignette</th>
<th>Pre-Test</th>
<th>Post-Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Answer</td>
<td>Score</td>
</tr>
<tr>
<td>1</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>B</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>B</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>B</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>No response</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In explaining her responses to vignette one on the introduction of parts of a fish, Aubrey felt that option C was a better way to start this lesson for both the pre- and post-tests. In the pre-test, she focused on this option being best because students were brainstorming and discovering before the real names and purposes were provided. In the post-test, Aubrey said students should be able to look at an actual fish when formulating their ideas of the purpose for the different parts of the fish. A concept map for Aubrey’s responses to vignette one is shown in Figure 13.

In both the pre- and post-tests, Aubrey answered vignette two on the introduction of force and motion with the Teacher Betty’s approach in letter B. She believed Teacher Betty employed the best approaches for achieving the science learning goals provided because her approaches allowed the students to discover the law “on their own” with guidance. She expanded upon this in the post-test to say that the teacher would be there specifically to ensure student understanding. The concept map for this vignette is shown in Figure 14.
In vignette three about discrepancies in data in an investigation of earthworms, Aubrey chose letter B for students to “suggest ways to resolve the issue” for both the pre- and post-tests. Aubrey described why she thought Ms. Lefevre should do this option during the earthworm investigation. She thought that this option was best because the students found the ways to resolve the issue and work on their problem solving skills. She explained in the pre-test that resolving the issue promotes higher-level reasoning. In the post-test, she elaborated on these ideas by saying that this option allowed students to work on critical thinking, in contrast to the teacher just telling the students the correct answer. Figure 15 shows the concept map for vignette three.

For vignette four about Ms. Jansen’s introduction to the phases of the moon through observations of the moon and sun and Ms. Jansen’s explanation of the concept, Aubrey answered B, indicating that she did not think that Ms. Jansen was off to “a good inquiry start.” She then suggested alternatives to what Ms. Jansen should do to provide a better start to an inquiry experience. In the pre-test she explained that the students should brainstorm their ideas, make a
hypothesis, and discover rather than just being told by their teacher. In the post-test, Aubrey thought that students should be shown the actual moon and then “come up” with ideas about why it is half full. Ms. Jansen’s approach could then be used after students’ ideas were expressed. Aubrey recognized that students might have difficulties with coming up with their own ideas. In such instances, the teacher could “point out” the location of the sun and encourage students to come up with ideas afterwards. Figure 16 contains the concept map for Aubrey’s vignette four.

**Figure 15.** POSITT vignette 3 for Aubrey.

Aubrey responded to vignette five with option B, which expressed that Ms. Chavez is off to a good start with her approach to model the phases of the moon with a flashlight in the room and then take students outside to view the moon. In the pre-test, Aubrey explained “this is good because it allows the students to make a hypothesis and then check it.” She thought that seeing the real moon was important, but the model allowed the students to check their predictions. In the post-test, she used different language to describe the same concept by expressing that the
students are coming up with ideas and testing them. Aubrey also explained that seeing the real moon may not always be possible because of the weather. In contrast, the flashlight model would always work. A concept map for vignette five is shown in Figure 17.

![Figure 17. POSITT vignette 5 for Aubrey.](image)

During the pre-test, Aubrey did not provide a response for either part of vignette six because she skipped this question. Therefore, there is no data to present. Figure 18 shows a concept map of the data gathered from the post-test only. Vignette six is about Mr. Yang’s introduction to the crescent moon and a student making an incorrect statement. Aubrey believed that Mr. Yang should perform option B to allow a student discussion where students use the information they already know to figure out the answer. Further, Aubrey explained that this approach would allow the student, Kim, to not feel bad about her misconception, and she might even be able to figure it out through the discussion.

![Figure 18. POSITT vignette 6 for Aubrey.](image)
The Analysis

The story of Aubrey’s experiences in teaching science through inquiry has been told. It is imperative to analyze her individual case study to find its meaning in relationship to the theoretical framework of Novak’s Theory of Human Constructivism\textsuperscript{12} and the research questions, specifically how her PCK, self-efficacy, and PNM knowledge associate with her practice.

Pedagogy of Science Inquiry Teaching Test

The POSITT provided an assessment of connections between the cognitive and the psychomotor domains in Novak’s framework as it assessed the teachers’ pedagogical knowledge teaching science through inquiry. Aubrey scored perfectly on the multiple-choice portion of the POSITT for the vignettes she provided answers to in both the pre- and post-tests (see Table 4).

Though her multiple-choice answers remained correct and constant, there were differences in Aubrey’s explanations between the pre- and post-tests. In the pre-test, Aubrey was not specific by what she meant by “discover,” nor did she stress the importance of observing the “real” phenomenon, as she did in the post-test. In vignette one, Aubrey said students should “discover” and “brainstorm” before being told the names of the parts of the fish. In the post-test, Aubrey explained that the students should actually look at fish to come up with ideas about the parts’ purposes. In vignette four, Aubrey again suggested students be allowed to “discover,” and in the post-test, she said students should go out to look at “the real moon” before brainstorming their ideas. Finally in vignette five, Aubrey did include the strength of the students seeing the real moon in the pre-test, but she placed her emphasis on the importance of the model. In the post-test, Aubrey explained that the flashlight model was good because of the assurance that the lesson could be done if the weather did not permit students to actually see the moon.

Throughout both the pre- and post-tests, Aubrey mentioned repeatedly the necessity of students doing things “on their own” in contrast to the teacher “just telling” them the answer. This conveyed that Aubrey believed inquiry meant students were the focus rather than the teacher. She did mention that it is important to her in vignette two that the teacher is there to provide guidance to students, which was further elaborated upon in the post-test that the teacher can help students when they have difficulties.
**Pedagogical Content Knowledge of Inquiry Science**

Through Aubrey’s experiences teaching math through inquiry, she approached the teaching of science with a good knowledge base of inquiry teaching, as evidenced by her POSITT results. Aubrey’s did make gains in her PCK of inquiry, which was evidenced by her POSITT results. In comparison to her pre-POSITT explanations, Aubrey was able to discuss specific activities that would allow students to “discover” concepts in December, like students looking at an actual fish and giving ideas about the purpose of the parts in vignette one. This portrayed an increase in the connection between the cognitive and psychomotor domains in Novak’s Theory of Human Constructivism.12 Aubrey also remained constant in her understanding that inquiry is focused on the students doing things and thinking “on their own.”

Unfortunately, Aubrey’s practice did not always align with this knowledge. The two learning cycles Aubrey chose were positive to her, but there were differences regarding the ease with which they were implemented. Aubrey thought “Sorting” was “a lot of fun” to do with her class, and during her post-interview, Aubrey shared that she had previously been teaching the concept of sorting prior to using the 5E learning cycle. Now consider, in contrast, her “more difficult” experience implementing “Materials Classification,” because her students had no prior experience with “materials.” She struggled to guide her students in the inquiry process because she was not sure which questions to ask or how to respond their ideas. She explained, “I don’t think I got across the gist of the lesson…I just didn’t know how to pull out the information I wanted them to get…I didn’t know how to lead them to a definition of those words. It is hard for me to define them let alone…in a way for them to understand them.” During the POSITT after her “Materials Classification” experience, Aubrey became intent upon the requirement that the teacher must help guide students in the inquiry process, but when discussing her actual practice, Aubrey said, “…it was really hard for me to guide them without telling them.” She also said, “You have to let them discover, but there’s also some things you have to show them or tell them.” This evidence showed a disconnect between her knowledge of pedagogy to teach science through inquiry and her actual teaching. It is imperative to note that Aubrey understood she had this disconnect as she “wouldn’t say [she] can always put it into practice well…[she is] in the learning stages of putting it into the practice.” Aubrey also had a desire to keep practicing with the 5E learning cycles to improve her practice.
Science Teaching Efficacy Beliefs Instrument

According to the overall STEBI scores, Aubrey’s teacher efficacy remained relatively constant as her score decreased by one from 91 in the pre-interview to 90 in the post-interview (see Table 3). This is also confirmed when viewing Aubrey’s scores on the PSTEBS and the STOES. Her score on the PSTEBS decreased from 45 to 43 and on the STOES increased by one at 46 to 47. Note, however, that Aubrey’s score on PSTEBS was lower than that of the STEOS on both tests, because the PSTEBS contains one more question with a possible five more points. The average of the average individual question score for each scale and the overall are shown in Table 5.

Table 5. Aubrey’s average score of individual questions.

<table>
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<tr>
<th></th>
<th>PSTEBS</th>
<th>STOES</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Test</td>
<td>3.46</td>
<td>3.83</td>
<td>3.64</td>
</tr>
<tr>
<td>Post-Test</td>
<td>3.31</td>
<td>3.92</td>
<td>3.60</td>
</tr>
</tbody>
</table>

These scores show that Aubrey had an average score between “uncertain” and positive for the PSTEBS and a relatively positive STOES average score. It may be deceiving to only look at the totaled and average scores of the scales, because when viewing the individual questions within the two scales, the responses provided were frequently varied within the two scales and between the pre- and post-tests (see Figures 9-12). For example, within the pre-test, Aubrey received scores between two and five on the STOES. Between the pre- and post-tests of each scale, there were differences of up to positive two and negative two.

In the PSTEBS, question five that states “I know the steps necessary to teach science concepts effectively” Aubrey changed her answer from disagree to agree between the pre- and post-tests. Question twenty-one stated, “Given a choice, I would not invite the principal to evaluate my science teaching,” and Aubrey initially disagreed to this question, however in the post-test, she agreed. An increase of two occurred for question twenty-five of the STOES, which states, “Even teachers with good science teaching abilities cannot help some kids learn science.” Her response changed from agree in the pre-test, to disagree in the post-test. Therefore, although Aubrey’s numerical STEBI results showed little change, there were several transitions within the questions. Another interesting occurrence is shown in question seventeen, where it was the only question scored as a 2 in both the pre- and post-tests. In both cases, Aubrey responded agree to
this negative statement: “I find it difficult to explain to students why science experiments work.” This could be an indication that she knew her content knowledge was weak.

Self-Efficacy of Teaching Science

Aubrey’s overall STEBI score remained relatively consistent, yet her scores on the individual questions within both scales showed many fluctuations in her self-efficacy. She did proclaim her confidence increased during her post-interview. Due in part to Aubrey’s experiences teaching through the 5E learning cycles, Aubrey increased in her knowledge of “the steps necessary to teach science concepts effectively.” After her 5E learning cycle experiences, Aubrey responded that she would not invite her principal into her classroom to evaluate her science teaching because personally, she is becoming less sure of her ability to teach science (as evidenced by the decrease in her PSTEBS scores). This contradicted her post-interview expression of increased confidence in teaching science. When discussing her confidence to teach science through inquiry, Aubrey expressed confidence in the inquiry process itself and understood it took time for students to learn. She expressed her desire to create her own learning cycles, which would include an elongated process, because she preferred “to build up the middle of [the learning cycle] before the evaluation.” As stated previously, Aubrey believed students require guidance, and this is difficult for her to implement with some content. Aubrey’s response to STEBI question twenty-five reveals that she believes with good teaching abilities it is possible to help students learn science. Aubrey expressed a desire to continue working on her science teaching abilities. Aubrey’s many fluctuations in responses on the STEBI suggested that she is somewhat uncertain in what she believes about herself and her abilities to have an impact on student learning. Aubrey’s uncertainty could be linked to the amount of time she has taught science. As Enochs and Riggs26 found, “Elementary teachers’ perceptions concerning their qualifications for teaching science were consistent with the amount of time they spent teaching it.” Again, she understood that she needed more time to practice teaching science through inquiry.

Particulate Nature of Matter

The PNM interview allowed the researcher access to what Aubrey “thought,” specifically about the particulate nature of matter. These interviews were analyzed for their meanings by
looking at the correctness of Aubrey’s conceptions, her certainty in her answers, and her consistency across her interviews.

**Correctness of Explanations**

When discussing particulate space for question one, Aubrey’s explanation in the pre-interview was correct that there is always some space in a solid. This portrayed that Aubrey did not have the common misconception that “particles are in contact with no empty space in between them.”\(^{14}\) In the post-interview, she also correctly explained, “Matter is made up of individual particles.” The relationship she explained for the particles in water had some scientific inconsistencies. She was correct in her conception that particles in gaseous water were furthest apart compared to liquid and frozen water. However, she explained that frozen water had particles closer together than in liquid water. Harrison and Treagust\(^{14}\) cited that the “spacing between solid-solid, liquid-liquid, and gas-gas particles is about 1:1:10.” Aubrey’s explanation was especially alarming in a discussion of the particles of water, because the density of ice is actually less than the density of liquid water.

When responding to question two, Aubrey explained that the water on the outside of the glass was called condensation. While this was true, Aubrey did not communicate an understanding of the verb “condense;” rather, she spoke of condensation as a synonym for water. In the pre-interview, she was correct when she said that the condensation comes from the air, which always contained water. It is correct that water is in the air, in contrast to the misconception that “[t]he coldness causes oxygen and hydrogen from the air [to] combine on the glass forming water.”\(^{53}\) Aubrey did not take into account the possibility that water may not “always” be in the air. Aubrey explained condensation came from “the cold,” but could not explain further. In the post-interview, she added that the cold “attracts” the water, thus forming the condensation on the outside of the glass. Although this conception cannot be directly compared to any of Mulford’s options, it shows the incorrect conception that the water had to be brought by the cold to the side of the glass, rather than being in contact with it in the gas form.

During her explanations of question three, Aubrey used the term “obvious” when referring to the 21 pounds she would think the answer should be, but then shied away from that answer because “that would be too easy.” This showed Aubrey’s conception of science, and the nature of matter, as difficult and complex. In the pre-interview, Aubrey did not choose the
“obvious answer,” but she chose an answer between 20 and 21 pounds. Though this is not precise, nor does it show a full understanding of the conservation of mass, she does reason well that the matter has changed form since the water dissolved the salt, but it was still there. She incorrectly linked the change in form to a possible decrease in mass. In the post-interview, she responded correctly, after some debate, with 21 pounds because she believed mass would be conserved in the dissolving process.

Aubrey correctly explained during the pre-interview to question four correctly that evaporated water would spread out within the magnified view. She also correctly drew water molecules still intact very similar to the picture in Mulford’s53 correct option “e.” During the post-interview, however, Aubrey explained incorrectly that the molecules evaporated and separated into the gaseous hydrogen and oxygen. Her drawing also displayed this incorrect conception, in addition to the misconception that hydrogen and oxygen are monatomic. Aubrey’s drawing did portray the individual hydrogen and oxygen atoms further apart and with fewer in the magnified view, showing that she understood that the particles in a gas are further apart than the particles in a liquid.

Finally Aubrey chose the correct option A for her answer in both the pre and post-interviews for question five. In the pre-interview, Aubrey expressed her understanding that gas particles are more spread out than in a liquid, consistent with the scientific view.14 She also explained the correct conception that gas particles are not static,14 rather move faster than particles in a liquid. Also in the pre-interview she showed the correct conception both in her choice of option A and with her words that particles heated to a gas do not increase in size.14 In the post-interview, her correct conceptions remained, but she explained that “they” take up more space than the liquid because they move faster, but again, do not increase in size. Aubrey’s use of “they” was in reference to the gas particles, and this will be further analyzed in the section entitled the Use of the Particulate Theory in Explanations.

Changes in Conceptions

Aubrey’s conceptions of the particulate level did change throughout the project with some improvements and some regressions. An improvement in her explanations occurred in question one, when Aubrey offered correctly that a gas was further apart than a liquid and a solid, even though she was not prompted to do so. Another improvement in explanations
occurred in question three where Aubrey dropped her initial belief that science was too complex to be “obvious.” Instead, she chose the correct answer of 21 pounds rather than the range between 20 and 21 pounds. However, Aubrey did regress in understanding with regard to questions one and four. In question one, Aubrey did not understand the particulate space in solids and liquids. She thought that particles in solid water were closer together than particles in liquid water, rather the reality is that ice is less dense than liquid water. With regard to changes on particulate space when water changes from a liquid to a gas, Aubrey explained in the pre-interview that the evaporated water simply spread out, but the water remained intact. However, this conception changed in her post-interview, as she explained that the water separated into oxygen and hydrogen, which she further depicted incorrectly as monatomic gases.

Use of the Particulate Theory in Explanations

Aubrey used the particulate theory only once during the pre-interview when she described the spreading out and increasing speed of the “particles” in question five. This was a correct use of the term particle. Question five was also written in terms of particles. Questions one and four do mention the particulate theory within the question; however, Aubrey did not repeat those terms. Questions two and three were written on the macroscopic level, and Aubrey made no mention of the particulate here. In the post-interview, Aubrey correctly used the term individual particles to describe matter at the particulate level. She then discussed the particles’ spacing, which as noted previously, was inconsistent with the scientific view. Aubrey also used the term “molecule” to inquire about her task in question four. It is unknown if she had a correct conception of the term because it is unknown if she referred to the water molecules already on the paper or if she was referring to what she would draw with the oxygen and hydrogen separated and monatomic. Again, for the two macroscopic level questions, Aubrey made no mention of the particulate theory, and also excluded it from her response to question five. These instances of use and correct use are found in Table 6 for Aubrey.
Table 6. Aubrey’s correct use of the particulate theory.

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<tr>
<th>Question</th>
<th>Pre-Interview Use</th>
<th>Pre-Interview Correct Use</th>
<th>Post-Interview Use</th>
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_Uncertainty with PNM as shown in Explanations_

As shown previously in Table 2, Aubrey had expressed uncertainty in some of her explanations within the particulate nature of matter interviews. In the pre-interview explanations of particulate space, she said, “I hope I am recalling correctly from when I was in school” and portrays that Aubrey operated on memory to answer this question and did not rely on reasoning from principles about PNM. Her response to question two was particularly interesting. Aubrey knew that the water on the outside of the glass was called condensation, but could not describe the “scientific reasoning.” As she tried to explain her choice of answers, she expressed several instances of uncertainty. In question three, Aubrey chose between 20 and 21 pounds in the pre-interview with no mentions of uncertainty. She did choose the “obvious” answer of 21 pounds in the post-interview, but not without two occurrences of uncertainty. It is interesting to note that her uncertainty increased as her answer became more specific. When referring to her answer of 21 pounds, she said, “That would be my guess…but it seems like that would be wrong because that seems really obvious…My guess would be 21.” In question four, Aubrey had expressed uncertainty in her answer of the water molecules remaining together in evaporated water and also her post-interview conception that the oxygen and hydrogen did come apart. In her post-interview, Aubrey even mentioned she knew she had changed her answer from the pre-interview. This shows she was not confident in the answers she provided to question four. Finally, Aubrey made no mention of uncertainty in question five where her conceptions remained constant and correct throughout the experience.

_Knowledge of the Particulate Nature of Matter_

Aubrey’s knowledge of the particulate nature of matter was not conceptually sound at the beginning of the research project, nor did it increase much during her experiences with the 5E
learning cycles. It became evident that Aubrey struggled to make connections between her knowledge at the particulate level of matter and the observable behaviors of the macroscopic world. Aubrey’s conception that gas particles are further apart than in a liquid held consistent throughout her interviews; however, she had difficulty relating this to the macroscopic level in question two on condensation. Though she knew that gas particles are further apart than a liquid, and further that a gas is less dense than a liquid, she could only attribute the formation of condensation to the “cold” in the pre-interview and in the post-interview, “the cold” physically “attract[ing]” the condensation. Therefore, in these instances, her limited knowledge of the particulate nature of matter could not be used to formulate explanations of the macroscopic. In kindergarten, the macroscopic is the focus of science. Nevertheless, it is important for teachers to have an understanding of the particulate in connection with the macroscopic. Aubrey’s regression in understanding regarding question four of the PNM interview cannot necessarily be connected to the 5E learning cycles as she did not work with the transition between liquids and gases because there are no standards for that within kindergarten. As shown in the discussion regarding her uncertainties, it is more likely that in both the pre- and the post-interviews her confidence in the answer she provided was low.

Aubrey’s experiences with the 5E learning cycles did cause her to think more deeply about the science content she was teaching, especially during the “Materials Classification” learning cycle. Aubrey enjoyed “Sorting” but had much more difficulty with implementing “Materials Classification.” Aubrey attributed her difficulty to not teaching the concept before – not to deficits in her own knowledge. Both Aubrey and the students had difficulty with the concepts and the activity. The students had problems coming up with definitions, and Aubrey was not satisfied with their descriptions of the materials. Aubrey also mentioned having conversations with other teachers about her questions. As discussed in the literature by the National Research Council, Aubrey learned through these reflections on her science inquiry teaching; for instance, Aubrey learned that a rubber band is not wood, metal, plastic, or cloth. Aubrey also grew in her understanding of her limited knowledge of the physical science standards. Kruse and Roehrig called for more experiences for teachers because “teachers have often not been exposed to situations that challenge the validity of their constructed ideas.” The “Materials Classification” 5E learning did challenge Aubrey, but she remained uncomfortable teaching the nature of matter physical science standards, which can be related to her incorrect
conceptions of the PNM and her uncertainty in the PNM. Aubrey indicated that she did not know the science content well. This showed that through “acting,” Aubrey’s experience was significant, yet she still lacks much of the needed knowledge in the PNM. It was very positive that Aubrey did have her first experience with actually trying to teach physical science indicator two of the Ohio’s Academic Content Standards.4

Conclusion

The experience of teaching science through the 5E learning cycles positively impacted Aubrey’s desire to teach science, and to do so through inquiry. As a Title I teacher for the first five years of her teaching career, Aubrey developed her language arts pedagogy, but had not had the opportunity to develop her pedagogy in teaching math, social studies, and science until later. Language arts was the focus of Aubrey’s classroom, and because of this, science was marginalized. She explained that in the half-day kindergarten, science is not a priority. She used this research project to aid her mainstreaming science in her classroom.

The findings of Aubrey’s case come together to mean that Aubrey was changing during the project. From the POSITT results, Aubrey had a sound understanding of the inquiry process prior to this project, yet she had difficulty actually implementing the 5E learning cycles on the nature of matter due to inadequate knowledge of the concepts. Aubrey was still unsure about what herself in reference to the affective domain, as shown in her STEBI results. Aubrey’s cognitive domain in reference to the particulate nature of matter was not strong as she held misconceptions and did not exhibit a deep understanding of the content. Aubrey’s development in the psychomotor domain was increasing, however she had drawbacks with a difficult learning cycle experience and began to stress the need for teacher guidance. Aubrey’s development in the connections between cognitive and psychomotor was found in her journals and POSITT results, as she was able to reflect on her experiences.
Chapter 5: Findings and Analysis of Janet’s Case

Introduction

In this chapter, the findings of the case study are presented for Janet followed by the analysis of her individual case. The findings are ordered in the same manner the findings analysis were ordered in Chapter 4 for Aubrey’s case. Again, concept maps are used throughout this chapter to represent Janet’s understandings of the PNM and the POSITT.

Description of Janet and her Interviews

Janet is one of two first grade teachers who participated in the research project. At the age of 56 years, she had been teaching for 33 years, 32 of those in this district. She earned a Master’s Degree from Miami University and a Bachelor’s Degree from Ohio State University. Though Janet had attended science workshops with some life science content, she explained that she has not taken a formal science class in 37 years. At the beginning of the project in spring 2007, Janet said that “[e]ven though I have a lot on my plate this time of the year, I am forcing myself to do [a 5E learning cycle] because science is important.”

During Janet’s first interview in April 2007, she explained that her primary focus and interest was in the teaching of language. When discussing the teaching of science, specifically physical science, Janet said that she was not very comfortable teaching the physical science standards. However, this was something she and the other teachers were working on in meetings with the district science coordinator. Janet really appreciated was the use of literature in conjunction with the science lessons. Although she might not have been completely comfortable teaching the physical science standards, she nevertheless liked teaching science because “students are motivated to learn and they can practice their reading and writing skills during science lessons.” In her view, science also allowed students opportunities to be active and to do hands-on activities. She explained that she disliked not “having enough time to…pull the science together.” She clarified that she does not dislike teaching science, but does dislike the amount of time required to do it. She used lessons developed by others, for instance the Science Curriculum Improvement Study, which was developed by Robert Karplus. When asked to describe a success in teaching science for her, she said, “Calling Science Alliance,” which is a partnership developed between the school district and Miami University. At the end of the
interview she said, “I want to do more science like Science Alliance, but the difficulty is gathering, setting up, and cleaning up the materials.” After her experiences using the 5E learning cycles, she explained, “I’ve really loved doing these experiments.” She also expressed her appreciation for the book *Apples, Bubbles, and Crystals: Your Science ABCs*, as a “recipe” for science. The book has a science experiment for every letter of the alphabet, and these books were distributed to teachers by faculty at Miami University during Science Week. Science Week is where one elementary grade per day from this school district travels to the university to participate in science experiments. When asked if she felt confident in teaching science in the past year, she said, “Most of the time, I was confident in the science.” Janet considered herself more knowledgeable with other standards, like math, than the science standards, because when “you read [the science standards] and then you think…now what did they say there.” When reflecting on her students science experiences in the last year in and out of the classroom, Janet said, “So I felt like once we had made a list of all things going on, I realized even though…I felt like I didn’t have science in my plans three times a week…I felt like we had gotten in a lot of science throughout the year. So I felt good about that.”

Janet initially felt the word “inquiry” had a positive connotation, but she expressed concern that the science textbook currently used by the school lacked inquiry lessons. She had prior experience with the concept in math because the curriculum had changed to inquiry-based lessons about 15 years ago. She expressed she was “comfortable” with teaching math through inquiry. At the end of the project Janet said that her knowledge of inquiry had changed in that “its not this deep secret or mystery or...that, you know, that it doesn’t have to be intricate.” She defined it as, “[y]ou don’t start telling the student this is what we are going to find out today. You start doing some explorations and then you talk about what have we learned from this and what did we discover.” The she explained that she “didn’t have the time to come up with inquiry lessons on [her] own,” but she was glad to teach them when provided to her “pre-packaged.” If she had the time, she said she would “maybe” be able to create 5E learning cycles for first graders.

**5E Learning Cycles**

Janet implemented two learning cycles throughout the year, “Learn with Magnets” in June 2007 and “Changing Properties” in January 2008. “Learn with Magnets” focused on
Ohio’s physical science indicator five for first grade, which states, “Explore the effects some objects have on others even when the two objects might not touch (e.g., magnets).” The science trade book *What Makes a Magnet* was used during the Explain portion after students created their own definition of a magnet. When deciding which 5E learning cycle to implement during a meeting with the researcher on May 31, 2007, Janet explained, “It is really hard to do science without a sink.” This was her reason for originally not choosing “Changing Properties” in the spring. In January 2008, Janet did choose to do the “Changing Properties” 5E learning cycle, which focused on Ohio’s physical science indicator three, which states, “Explore and observe that things can be done to materials to change their properties (e.g., heating, freezing, mixing, cutting, wetting, dissolving, bending and exposing to light).” After exploring these properties through a series of six stations, the students created definitions of the methods they explored during the Explain portion. Then the science trade book *Pancakes, Pancakes!* was read to elaborate on the concepts. The students were to pick out the instances in the book that illustrated the methods for changing properties discussed in the Explore and Explain. Janet did this 5E learning cycle on one day with her class.

**Reflective Journals**

During the “Learn with Magnets” 5E learning cycle, Janet kept a journal. She noted during the Engage and Explore portions, “the first graders were highly motivated and on task.” Janet wrote that she wished she had read the literature about magnets prior to the learning cycle, but the class did have a great discussion about magnets. Afterwards, Janet explained that during the Explore portion, students tried to explain what magnets were and where magnets came from. This suggested to her that the students were actively thinking about the topic. She also reflected on the nature of first graders: “First graders think their prediction has to be the ‘right answer’ so it is challenging for them to be ‘risk takers.’” When discussing the use of the literature, Janet said she would rather use the book as a reference than read the whole book. Janet reflected on the length of time spent on the learning cycle, and explained that when she would do this particular 5E learning cycle next year, she would divide it over two days in order to spend more time on sections to avoid being “rushed” at the end. She wrote, “I loved this lesson.” She did acknowledge the time it took to setup, but Janet explained it could be planned ahead of time. Finally, Janet spoke to the use of children’s literature to teach science explaining that she thinks
it is “very effective,” but students can be distracted by the book if everything in the book does not pertain to the learning cycle.

Janet also reflected on her experiences with the “Changing Properties” 5E learning cycle. Janet explained that she did not get to do the Explore portion as stations, but rather, did several as demonstrations. She chose not to do the stations because she explained, “I have a pretty tough class to handle this year.” She elaborated on this and expressed, “I could see if you did this in the spring, if you had a couple parents, if the kids were more mature, you could definitely do this as stations.” This choice was made “more for management.” The demonstrations included dissolving salt in water, observing paperclips and rice as a mixture, a Popsicle melting, and the chocolate bar exposed to a lamp. Every student did have the opportunity to bend a paperclip and work in groups to bend the hanger. The students really enjoyed this activity, and Janet reflected “…that it had never occurred to them that a paper clip and a hanger were made out of wire.” Every student was given the opportunity to try wetting a coin, piece of paper, and cardboard. Before the Evaluate portion started, Janet discussed with her class what they had done to their materials. She thought that “[t]hey understood all that…but Play-Doh for a kid is just love.” Therefore, during the Evaluate portion, “[t]hey would cut it with their scissors, they would roll it, they would squish it, but nobody would put it in water because it’s their Play-Doh.” She explained that none of her students “would risk making a permanent change, which is what they thought the water would do.” In order for the students to still see what would happen, Janet did a demonstration for them. In reflecting upon the Evaluate part of the cycle, she felt that the students working with Play-Doh was “very motivating” and that it was a “good experience” for them. Janet explained, “They really loved doing the experiments. I want to try to do more.”

Finally, Janet commented on the use of literature with this 5E learning cycle:

The book was good. A lot of them had heard it before which was ok…I think they got especially the part about the flour and the egg and the liquid, the liquid becoming a solid with the temperature added and the liquid being turned into the solid. They also decided that was way too much work to have a pancake…I thought it was probably a good enough experiment to stand alone without the literature.
**Particulate Nature of Matter Interview**

Janet first participated in the PNM interview in June 2007 and second in January 2008, after implementing two 5E learning cycles into her classroom. For question one on particulate space and orientation, Janet explained in the pre-interview that in a solid there was “little space” between the particles and that “they” were really close together. This conception was elaborated in the post-interview where Janet explained that a liquid was “a little more apart” and a gas was “even further apart” in comparison to a solid. Her conceptions of the particulate nature of matter are shown in Figure 19.

![Figure 19. PNM Question 1 for Janet.](image)

In the pre-interview, Janet explained her answer to question two by saying that water was drawn from the air to the glass because of a difference in temperature. In the post-interview, she described that “moisture” was drawn from the air on the outside of the glass because of a change in temperature. This change in temperature was between the inside of the glass, which she felt was colder than the outside of the glass. A concept map for this question is shown in Figure 20.

![Figure 20. PNM Question 2 for Janet.](image)
For question three, Janet said in the pre-interview that the mass of the water would stay the same at 20 pounds because the salt completely dissolved in the water. In the post-interview, Janet explained that she knew the salt completely dissolves in water because she had just done this the day before during the 5E learning cycle. She first explained that the mass would remain 20 pounds, but then reasoned that did not make sense to her. She explained that the “salt went into the water” and even though it dissolved, it became a solution and still would have “some weight.” Her final answer to the post-interview was 21 pounds for the salt and water. Figure 21 portrays Janet’s understanding of salt dissolving in water.

For question four on the behavior of particles of evaporated water, Janet explained that she knew that water is “H₂O,” which contains “two molecules of hydrogen attached to a molecule of oxygen.” Also in the pre-interview, she was not sure if the hydrogen or if the oxygen “goes” from the water, which was her way of explaining separation of the water leaving behind either the oxygen or the hydrogen. She reasoned they would separate because “something changes” in order for the phase change to occur. Janet also explained that oxygen and hydrogen are both gases. For the post-interview, she began by explaining her uncertainty about whether the “gases go out” or if the water does. She still felt that the water separated in some way or “breaking apart” with one part of the water “leaving.” Figure 22 shows a concept map presenting Janet’s understanding of evaporated water.
Finally, when responding to question five, Janet explained that when a liquid is heated to a gas, it becomes like view B, which depicts the particles expanding. This is what the question asked. However, Janet explained that if it is “evaporated” it becomes like A, where the particles spread out and do not expand. In the post-interview, Janet did not give a definitive answer. She related the question to a tea kettle but determined she could not use this to infer about what happens to the particles, whether they expand or spread out. She said, “You know, I don’t know what happens to the particles. If they become A or if they become B, I don’t know.” This is shown in Figure 23.
Use of Particulate Theory in Explanations

During Janet’s PNM interviews, she used the particulate theory in two instances, as shown in Table 7. She used the word “molecule” to describe both oxygen and hydrogen in water during the pre-interview. In her post-interview responses to question four, Janet used the terms oxygen and hydrogen; however, she did not use terms such as particle, atom, or molecule even though the question does contain particulate drawings. In the post-interview, Janet used “particles” to explain question five. She admitted that she did not know what happened to the particles when they were heated to a gas.

Table 7. Janet’s use of the particulate theory.

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<th>Post-Interview</th>
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Uncertainty with PNM as shown in Explanations

Janet expressed uncertainty in her explanations throughout her PNM interviews, as shown in Table 8.

Table 8. Uncertainty in the PNM Explanations for Janet.

<table>
<thead>
<tr>
<th>Question</th>
<th>Pre-Interview</th>
<th>Post-Interview</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>2</td>
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<tr>
<td>3</td>
<td>3</td>
<td>5</td>
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<tr>
<td>4</td>
<td>6</td>
<td>4</td>
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<tr>
<td>5</td>
<td>6</td>
<td>4</td>
</tr>
</tbody>
</table>

During her first interview response to question three on salt dissolving in water, Janet asked, “Is salt heavier than regular water? I don’t know. Maybe it is. I told you I am not very good at this.” In her explanation of question four on the evaporation of water, she said, “So I am guessing that oxygen and hydrogen separate.” Janet was more uncertain throughout the second interview, where she explained her understanding of question one on particulate space and orientation, “Well I am just guessing here that a gas is further apart…No I don’t know. I am just guessing.” To question three, she explained her answer and followed it with, “But I really don’t have any clue.”

Science Teaching Efficacy Beliefs Instrument

Janet first took the STEBI assessment in April 2007 prior to implementing her first 5E learning cycle, and then took the STEBI again in January 2008 after her second learning cycle experience in her classroom. The scores of her pre- and post-tests are shown in Table 9.

Table 9. STEBI results for Janet.

<table>
<thead>
<tr>
<th></th>
<th>PSTEBS</th>
<th>STOES</th>
<th>Overall Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Test</td>
<td>48</td>
<td>44</td>
<td>92</td>
</tr>
<tr>
<td>Post-Test</td>
<td>52</td>
<td>46</td>
<td>98</td>
</tr>
</tbody>
</table>

Janet’s overall score increased by 6 between the pre-test and the post-test, which was due to an increase of 4 in the PSTEBS and 2 in the STOES. Figure 24 and Figure 25 provide information on the individual questions within the PSTEBS and the STOES, respectively. Three questions in the PSTEBS increased to cause the 4 point increase in the scale score, the remaining 10 questions remained constant. The change in the STOES score was due to a 1 point increase in each of two questions.
Figure 24. Pre- and Post-PSTEBS Individual Question Scores for Janet.

Figure 25. Pre- and Post-STOES Individual Question Scores for Janet.
Pedagogy of Science Inquiry Teaching Test

Janet participated in the POSITT in June 2007 prior to her first experience with a 5E learning cycle and then responded a second time on January 2008 after a second 5E learning cycle. The answers she provided to the first-tier, multiple-choice questions in the vignettes and her scores are shown in Table 10. Her answers to the second-tier of the vignettes are provided in the concept maps included in Figures 26-31.

Table 10. POSITT multiple-choice responses for Janet.

<table>
<thead>
<tr>
<th>Vignette</th>
<th>Pre-Test</th>
<th>Post-Test</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Answer</td>
<td>Score</td>
</tr>
<tr>
<td>1</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>B</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>B</td>
<td>1</td>
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<tr>
<td>5</td>
<td>B</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>B</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

For vignette one on the parts of the fish, Janet chose multiple-choice option C that the lesson was not off to a good start. She explained her choice by saying that she did not think the lesson was off to a good start. In the pre-test, Janet explained that the students should be given the opportunity to ask questions, to gather information through resources, and to communicate their findings. In the post-test, she explained this process in terms of the 5E learning cycle. She expressed a need for an activity “more interesting than a [overhead] transparency to engage the students.” She then suggested activities that would allow the students to “explore the relationship between the form and function” of the parts of the fish. These conceptions are mapped out in Figure 26.

In both the pre- and post-tests, Janet responded to vignette two on the relationship between force and motion with multiple-choice option B that this was good start. In the pre-test, she thought that Teacher Betty guided students to the “discovery” of the force concept. In the post-interview, she explained her choice further by describing how Teacher Betty’s approach fits into four of the 5Es, the Engage, Explore, Explain, and Evaluate. A concept map for Janet’s discussion of vignette two is shown in Figure 27.
For Ms. Lefevre’s earthworm investigation in vignette three, Janet chose letter B for both the pre- and post-tests. On both tests, she explained that this option was best because it allowed for students to develop their investigating skills. For the pre-test, Janet also felt that students were developing additional skills like discussing the science, which mimicked what happened
During real-life scientific investigations. During the post-interview, in addition to skills in investigating, Janet thought that the students worked on developing their observing, recording, and pattern-seeking skills as they applied them to the investigation. A concept map of Janet’s understanding of vignette three is shown in Figure 28.

In vignette four on the phases of the moon, Janet chose option B, which indicated that Ms. Jansen was not off to a good start for her inquiry activity. In the pre-test, she explained it was better to see the real moon rather than viewing a book diagram. However, in contrast to Ms. Jansen telling the students, Janet thought that students should think “on their own.” In the post-test, she began to describe a 5E learning cycle that Ms. Jansen could use to investigate the phases of the moon. She included that “[Ms. Jansen] could take them outside to see the real thing as the engage activity and then have them wonder about it and discuss possible ideas” (emphasis original). These responses are shown in the concept map in Figure 29.

For vignette five on Ms. Chavez’s approach to model the phases of the moon, Janet chose B for both the pre- and post-test, indicating Ms. Chavaz was off to a good start. In the pre-test, she thought that Ms. Chavez had started well because she was encouraging and guiding students in discussion and exploration. In the post-test, Janet expressed this activity would be “engaging” for students, but difficult to be done during the day at school. The researcher’s concept map is shown in Figure 30.
During the pre-test on the final vignette six, Janet selected the multiple-choice response B explaining Mr. Yang was encouraging students to think, investigate, and discuss. During the post-test, Janet did not provide a multiple-choice response or a response to the second question of asking for an explanation of her choice vignette six, because she chose to leave that question blank. Therefore, there was no data collected for this vignette. Figure 31 shows a concept map of the data gathered from the pre-test only.
**The Analysis**

The findings of Janet’s experiences of implementing the 5E learning cycles have been told. These findings will now be analyzed for her individual case in order to find its meaning in relationship to the theoretical framework of Novak’s Theory of Human Constructivism and the research questions.

**Pedagogy of Science Inquiry Teaching Test**

As an assessment of the connection between Novak’s cognitive and psychomotor domains, Janet participated in the POSITT. For the multiple-choice portion of each vignette, Janet responded perfectly with the exception to question six, which she chose not to answer in the post-test. One of the prominent differences in Janet’s explanations between the pre- and post-tests was in the words she used. In several instances during the post-POSITT, Janet used the Es of the learning cycle to describe why she thought that vignette or option was or was not the best. In question one, Janet did not think the lesson was off to a good start and suggested the use of Engage and Explore activities. In vignette two, Janet used four of the 5Es to describe why she thought choice B was the best; in vignettes four and five, Janet describes how seeing the moon would be a good way to start because it would act as the Engage for students. Due in large part to her use of the 5E learning cycle stages in her post-descriptions, Janet’s pre- and post-test concept maps overlapped very little.

**Pedagogical Content Knowledge of Inquiry Science**

From the beginning of the project, Janet had knowledge of inquiry due to her prior experiences with the math curriculum. An example of this is shown in her pre-POSITT where she explained,
“[I]t’s good that they are looking at the real thing rather than a book diagram, [but Ms. Jansen] is ‘telling’ them rather than letting them think about what’s happening on their own.” Janet understood that the science textbook did not contain inquiry, but also expressed that she did not have the time to create and set-up her own science inquiry experiments. If she had the time, she believed that she might be able to develop 5E learning cycles but only for first graders. This showed possible uncertainty in Janet’s ability to connect the inquiry with the requisite science knowledge to create the learning cycles. Furthermore, in practice, Janet relied on “pre-packaged” science to guide her science conversations. Janet preferred to use outside resources such as Science Alliance rather than allotting three times per week for science. There were times when Janet expressed barriers to doing science that were beyond her control; for instance, Janet did not originally choose to do the “Changing Properties” learning cycle because she did have a sink to get water from in her room.

Janet’s experiences with the learning cycles enabled her to analyze the POSITT questions differently than she did in the pre-POSITT. Janet reflected through journals and in her post-interview upon her opportunity to “act” through the two 5E learning cycles she implemented. She said that she “… loved this lesson” after “Learn with Magnets,” and wrote after “Changing Properties,” “[the students] really loved doing the experiments. I want to try to do more.” In short, Janet believed that her experiences with the learning cycles were positive for both her and her students. Janet’s experiences also revealed some disconnects between her knowledge of inquiry and her practice. Though during the pre-POSITT, Janet explained in vignette four that the teacher should allow students to think on their own in contrast to the teacher telling the students, Janet reflected on the “Learn with Magnets” learning cycle that the literature should be read first instead of after the exploration. This suggested that Janet wanted her students to have prior knowledge of what they would be exploring instead of reading about the concept after the exploration. The first of the three conditions for meaningful learning in Novak’s Theory of Education is that there exists “some relevant prior knowledge”1 for use of incorporating the new information. It is unclear if Janet’s motivation for reading the book first was to cancel the inquiry or to provide some knowledge of magnets due to students having none. But then in the post-interview, Janet showed growth in this when she explained inquiry: “You don’t start telling the student this is what we are going to find out today. You start doing some explorations and then you talk about what have we learned from this and what did we discover.” Janet also chose
to modify the “Changing Properties” learning cycle to a more teacher-centered approach because of classroom management difficulties and explained, “I didn’t get to do them as stations…The salt…the rice and paperclips…and the popsicle [I did]…as a demonstration.” Finally, Janet’s experiences with the 5E learning cycles helped her change her knowledge of inquiry in that “[inquiry is] not this deep secret or mystery or...that, you know, that it doesn’t have to be intricate.” As described by Water-Adams, “understanding at a theoretical level does not predict eventual practice.”

Science Teaching Efficacy Beliefs Instrument

Janet’s STEBI scores indicate an increase in her self-efficacy during the project. Her overall score increased from 92 in the pre-interview to 98 in the post-interview (see Table 9). This is due to increased scores in both the PSTEBS and the STOES. It is noteworthy that Janet had no instance of decreased score on individual items between the pre- and post-tests. Janet’s PSTEBS changed due to increased scores on three questions, and the STOES improved due to increased scores on two questions. Table 11 shows that Janet’s average score on individual questions was slightly higher on the PSTEBS than in the STOES in both the pre- and post-tests.

<table>
<thead>
<tr>
<th></th>
<th>PSTEBS</th>
<th>STOES</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Test</td>
<td>3.69</td>
<td>3.67</td>
<td>3.68</td>
</tr>
<tr>
<td>Post-Test</td>
<td>4.00</td>
<td>3.83</td>
<td>3.92</td>
</tr>
</tbody>
</table>

Though Janet’s scores increased on five different questions, there was one instance in question three on the PSTEBS where the increase was by 2. Question three stated, “Even when I try very hard, I don’t teach science as well as I do most subjects.” In the pre-interview, Janet agreed to this statement but transitioned to disagree in the post-interview. Other interesting observations included the fact that there were only two questions, eleven and thirteen, on the post-interview that Janet scored lower than a 4. Question eleven read, “When a low achieving child progresses in science, it is usually due to extra attention given by the teacher,” and question thirteen stated, “Increased effort in science teaching produces little change in some students' science achievement.” Both these questions were contained in the STOES and were scored as uncertain in both the pre- and post-tests.
Self-Efficacy of Teaching Science

Throughout the project, Janet’s efficacy in teaching science increased as evidenced by her responses to the STEBI. Janet was confident about teaching science to her students, which contrasts against her inquiry experiences. Janet’s self-efficacy increased, yet she desired to read the trade book to her class prior to the learning cycle. Janet’s increase in self-efficacy did not correlate with her modifications in the “Changing Properties” 5E learning cycle experience. This could be attributed to Woolfolk’s connection between efficacy and practice, where she said, “For a teacher with a low efficacy, they will feel the desire to take control of classroom behavior and use negative sanctions to increase students performance.” The conundrum is then that Janet had an increasing and relatively positive self-efficacy, yet did not feel comfortable allowing her students freedom to explore. This further conveyed the disconnection for Janet between the cognitive and affective domains in Novak’s Human Constructivism. Bandura discussed that beliefs a teacher holds are only significant if they then can be executed. Janet believed in herself, but she did not connect her beliefs to her actual practice, thereby hindering her execution. It can be suggested that Janet compensated for this disconnect through the use of Science Alliance and “pre-packaged” science. Therefore, there existed a disconnect between Janet’s affective domain and the psychomotor domain.

Particulate Nature of Matter

Janet’s participation in the PNM interview allowed the researchers access to her conceptions of matter at the particulate level, which constituted the “think” in Novak’s Theory of Human Constructivism. Janet’s explanations provided during these interviews were analyzed for correctness of conceptions, certainty in her answers, and consistency across her interviews.

Correctness of Explanations

Janet explained her understanding of matter in the pre-interview that in a solid there is little space and that “they” are really close together. From this response, it is unclear if Janet believed there was empty space or if she held the misconception that “particles are in contact with no empty space in between them.” This conception was elaborated upon in the post-interview when Janet explained that a liquid is “a little more apart” than a solid and a “gas is even further apart” than the liquid. Again, it was not known if Janet believed there was space in
a solid as she explained that a solid was “really close together.” Janet’s comparison of increased space in a liquid when compared to a solid is evidence of the misconception discussed by Harrison and Treagust\textsuperscript{14} in contrast to the actual “spacing between solid-solid, liquid-liquid, and gas-gas particles is about 1:1:10.” Janet’s conceptions are even further from the correct conception of the most commonly used substance in the elementary grades, water, where liquid water is actually more dense than water as a solid.\textsuperscript{63}

For question two in the PNM pre-interview, Janet explained correctly that water was from the air and drawn to the glass due to a difference in temperature. In the post-interview, she described that “moisture” was drawn from the air to the outside of the glass because of a change in temperature between the colder inside of the glass and warmer outside of the glass. Janet understood the cause of the appearance of the water or moisture. Janet did not use the noun “condensation” or the verb “condense” in her explanations. She also did not use the term “vapor” to describe the water in the air, and thus, her answer did not align completely with the correct response of “[w]ater vapor condenses from the air” from the Chemical Concepts Inventory (CCI) by Mulford.\textsuperscript{53} but conceptually, Janet did understand that the air was the source of the water and that the water on the glass results from the temperature change.

During her response to question three in the PNM pre-interview, Janet incorrectly said that the mass of the salt water solution would remain constant at 20 pounds because of the salt completely dissolving in the water. Janet’s response was the same as distracter “b” from the CCI.\textsuperscript{53} In the post-interview, Janet’s final answer of 21 pounds was correct and offers evidence that she understands the concept of the conservation of mass. Janet explained the dissolving process macroscopically by the “salt went into the water.” She also explained the salt and water became “a solution,” which aided in her explanation for why she thought the mass was 21 pounds.

For question four, Janet explained correctly in the pre-interview that she knew that water has the formula H\textsubscript{2}O but then incorrectly used the term “molecule” to describe the individual oxygen and hydrogen atoms within the water molecule. She did convey that she knew there was a ratio of 2:1 between hydrogen and oxygen. In both the pre- and post-interviews, Janet conveyed the misconception that when water is evaporated, the oxygen and hydrogen present in “H-two-O” separate into their constituent gases. Janet used the verb “go” to describe the process of evaporation, but when asked she was not sure what “went” during both interviews. In the pre-
interview, Janet discussed how she believed that the hydrogen or oxygen “went out” from the water and left the other (hydrogen or oxygen) behind. In the post-interview, she also discussed “the gases” or “the water…going out.” Janet’s drawing resembled magnified view “d” from Mulford’s multiple choice options and contained two hydrogen atoms for each oxygen atom, incorporating the commonly held misconception that hydrogen and oxygen are monatomic gases. Further, Janet reasoned that “they” would separate because “something changes” in order to change from a liquid to a gas but could not further describe this change. Throughout her explanations, however, Janet did correctly believe that oxygen and hydrogen were both gases.

Finally, in Janet’s explanation of question five, she differentiated between the processes of heating and evaporation. She explained that when a liquid is heated to a gas, it becomes like view B with the particles themselves expanding; however, she explained that if it “evaporated” it becomes like A with the particles spreading out. This suggested that Janet believed that heat was not required to cause evaporation. In the post-interview, Janet could not give a definitive answer due to her inability to use the macroscopic example of tea kettle to deduce a response. Although she tried to relate the question to a tea kettle, she could not use those macroscopic observations to infer what occurred at the particulate level.

Changes in Conceptions

Janet’s understanding of the particulate nature of matter did transition between the two interviews. An improvement in explanations occurred in question one, when prompted. Janet correctly explained that a gas was further apart in comparison to liquid and a solid. In question three, Janet portrayed an increased understanding that mass is conserved when salt is dissolved in water. In order to respond to this question, Janet had recalled her experience with dissolving salt in water the previous day during the 5E learning cycle “Changing Properties.” Not all changes were positive, though. Janet incorrectly stated that there is a difference in space between the particles in a solid and in a liquid. Janet’s explanation to question five transitioned from the incorrect option to complete uncertainty about her response.

Use of the Particulate Theory in Explanations

Janet used particulate terms within her explanations during the PNM interview in only one instance in each the pre-interview and post-interview. In the pre-interview, she used the
term “molecule” during her explanation of question four to describe the hydrogen and oxygen atoms within the water molecule. In the post-interview, Janet used the term “particles” when expressing her uncertainty as to what effect heating would have. Both of these questions are written in terms of particles. These two occurrences of the particulate are shown in Table 12 and are not considered the correct use due to conceptions within those responses were incorrect.

<table>
<thead>
<tr>
<th>Table 12. Janet’s correct use of the particulate theory.</th>
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<tbody>
<tr>
<td><strong>Question</strong></td>
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<tr>
<td>--------------</td>
</tr>
<tr>
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<td>3</td>
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<td>4</td>
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<td>5</td>
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</tbody>
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_Uncertainty with PNM as shown in Explanations_

When looking at Table 8, it is clear that Janet had a large amount of uncertainty in her explanations to questions within the PNM interview. In fact, there was not a single question in which Janet did not express some level of uncertainty in her explanations. It should be noted, however, that Janet’s uncertainty in question one in the post-interview was due largely in part to the researcher asking Janet further questions about the differences in the solid, liquid, and gas. Janet was not able to answer those questions confidently.

Knowledge of the Particulate Nature of Matter

It was very important to Janet that it was known she had not enrolled in a formal science class for 37 years. This was her reason for why she lacked of depth of knowledge when answering questions during the PNM interview. Janet’s knowledge of the PNM was not conceptually sound with many gaps in understanding, but she did make some conceptual gains through her experiences. She used her 5E learning cycle experience of dissolving salt in water to correctly answer question three during the PNM interview. Even with these gains, Janet still expressed much uncertainty in her explanations. Although Janet provided the correct explanation that the particles in a solid and liquid are closer together in comparison to those of a gas, Janet was not comfortable using particulate terms to describe observable phenomena in questions two and three. As discussed in the research literature by Boo, there were
inconsistencies in Janet’s explanations of questions three and four. In question three, Janet explained that there is water in the air that is drawn to the side of the glass. In contrast to this, Janet expressed that in order for water to evaporate to a gas, the oxygen and hydrogen must separate rather than remaining as water in the air. This showed a disconnection between her understanding at the macroscopic and at the particulate levels. Janet’s misconceptions did show some persistence within her explanations. Janet believed “something had to happen” in question four, and then in question five her response of “B” of the particles actually expanding could be attributed to this same reasoning.

Janet’s knowledge of the PNM can be analyzed in conjunction with her inquiry practices. It was positive that Janet was able to make a connection between her “Changing Properties” learning cycle experience and the dissolution of salt in water on the PNM interview, however this was only one instance where her cognitive and psychomotor domains were connected. Janet did express that “[m]ost of the time, [she] was confident in the science,” but could not use her knowledge about the particulate nature of matter to interpret the Ohio physical science indicators for first grade: “You read them and then you…think…now what did they say there.” When discussing the use of Pancakes, Pancakes, Janet expressed that she did not feel the literature was necessary for the learning cycle. This was quite different than her feelings about the “Learn with Magnets” learning cycle because she wanted that first. It is interesting to note that the placement of the trade books in the learning cycles, as the first 5E on magnets has the book being read in the Explain and in the second 5E, the book is read in the elaborate. This would suggest reliance on the book as the Explain, but if it does not do the Explain, there is no need for the trade book. It is difficult to base this claim solely on these two instances. Finally, Janet expressed, “I just want to get my hands on more…pre-packaged lessons that go with the standards.” This can be correlated to Janet’s uncertainty in science, particularly with the PNM, as she desired to have everything given to her rather than her creating the lessons. This can also be correlated to the amount of time she has to create these learning cycles. Therefore, Janet’s knowledge of the PNM did affect her abilities to teach science within her classroom.

**Conclusion**

Even after 33 years of teaching science, Janet was willing and determined to incorporate more science into her classroom. Janet explained that she enjoyed teaching science and desired
to teach it “like Science Alliance;” however, her major obstacle was “…gathering, setting up, and cleaning up the materials.” Janet was committed to teaching science, and this was shown through her motivation when she said at the beginning of the project that “[e]ven though I have a lot on my plate this time of the year, I am forcing myself to do [a 5E learning cycle] because science is important.”

In conclusion, the findings and meanings of Janet’s case in conjunction with Novak’s Theory of Human Constructivism include that Janet had a sound knowledge of inquiry and an increasing confidence in herself to teach science. However, this was not well connected to her psychomotor or cognitive domains. Janet did not believe she could manage her class while doing the stations, and therefore, Janet reduced the level of inquiry significantly by modifying much of the student exploration to teacher demonstrations. The disconnect between Janet’s affective and cognitive domain was due to her knowledge of the PNM was lacking, but at the same time, Janet did feel more confident about teaching science. Janet was confident about teaching science to her students, which contrasts strongly against the uncertainty in her responses within the PNM interview and the uncertainty expressed with regard to interpreting the science indicators. Therefore, Janet does not realize that her science knowledge was lacking. Finally, Janet also had an improving knowledge of inquiry as shown by her POSITT results and use of the 5E learning cycle as a tool for analysis of inquiry, but that did not predict her practice of eliminating student hands-on activities during the “Changing Properties” 5E learning cycle.
Chapter 6: Findings and Analysis of Hannah’s Case

Introduction

This chapter presents the findings of Hannah’s case study and the analysis of her individual case. The findings are ordered in the same way Chapters 4 and 5 with a description of Hannah and her responses to interview questions, descriptions of the 5E learning cycles used in her classroom, her journal entries after the 5E learning cycles, responses to the PNM interview, STEBI results, and POSITT results. Concept maps are used to represent Hannah’s understandings of the PNM and the POSITT.

Description of Hannah and her Interviews

Hannah was also a first grade teacher participating in the study. Hannah was 52 years old and had been teaching for 21 years, 15 of which were within the district. Her highest degree attained was a master’s degree from Miami University, and she earned her Bachelor’s degree from the University of Wisconsin-Madison. During her time in the district, Hannah’s position has changed several times. She has been a second grade teacher, the curriculum director for language arts for three years and now is teaching again but in first grade. Hannah is member of a scientific family, as her husband is a chemist.

Initially in May 2007, Hannah said language arts and math were the subjects of primary interest to her, because “in first grade, that reading is just so crucial.” She mentioned this was partly due to the fact that in third grade there was the Ohio Achievement Test in math and reading. When speaking about her level of comfort teaching the physical science standards, Hannah said:

I am comfortable with doing it. I am not comfortable in how I am doing it because since it’s not a priority I don’t spend the amount of time to do it as well as… to do it like I want to do it. I don’t want to read the kids a big book and say see this ice cube, it’s melting. I don’t want to do that, but…that’s how it is.

Hannah really enjoyed teaching science because her students got excited and were curious, but she disliked that she had not been able to teach the way she wanted to due to class time and time for planning. In the middle of December 2007, Hannah expressed said, “I feel more confident now teaching science in first grade than I did last year because this is my second year, but I don’t
feel as confident as I did when I taught [science at] other grade levels.”  She attributed this to not knowing the indicators as well and that she couldn’t “see how they all fit together as well.”

Hannah commented on the effects of teaching higher elementary grades, as “it is hard for [her] sometimes to bring stuff down low enough.”  At times, she makes things “too complex” because she wants her students to “know.”  She summarized when she said, “I have a hard time feeling like I am teaching enough science when they just really need to explore the basics.”

Hannah provided her thoughts on inquiry at the outset of the project.  When thinking of the word inquiry, she thought of the word “discovery or investigation.”  Then through this discovery or investigation, “the kids make predictions or hypotheses about why something work[s] or what’s going to happen and going through the questioning.  It’s not just me questioning but them getting to the point where they can ask the questions.”  She felt this was positive, especially when used “in all the subjects areas…then you see kids start making connections across the subject areas.”  Hannah explained that she “hope[d]” she used inquiry in her classroom but was not as good at it as she would like to be.  Hannah also said that she was beginning to think “if you can allow yourself to do that with kids…they will continually surprise you with what they can come up with.  But it takes longer and so it is harder to hold yourself back as a teacher.”  She said this positively affected the students as well, because “they [were] surprised at what they [did], and it [was] what they’ve done, not what you’ve done, and so it empower[ed] the kid.”  After implementing her two 5E learning cycles, Hannah elaborated on her previous conception of inquiry when she said, “It gets the kids thinking about what they’re thinking…if they really thought about it, they are able to extend it to something else.”  She discussed a flaw in teachers, as they think the thinking is “cute,” but teachers do not “really honor the thinking.”  As first graders, “the conclusions they may come up with may not be very sophisticated but it’s the process that’s important also.”  Hannah concluded by saying that she believed “[students] have a deeper understanding of what it means instead of somebody than just telling them.”  This was also connected to her increased understanding of inquiry throughout the project across all subject areas, because she said, “I think once the kids have the opportunity to do [inquiry] everywhere, they approach learning differently…it becomes easier to get them to think about things and to be able to give reasons for why they think of something.”
5E Learning Cycles

Hannah also implemented two 5E learning cycles during the project, which were “Changing Properties” in June 2007 and “Learn with Magnets” in December 2007. These were the same learning cycles chosen by Janet except done in reverse order; please refer to the descriptions of these learning cycles within Janet’s case. During a meeting with Hannah on May 28, 2007 where she decided which 5E learning cycle she would use in her classroom, she commented that she was “…glad you [KMN] started with the physical sciences because teachers are more comfortable teaching life sciences like growing plants and life cycles.” Hannah chose “Changing Properties,” and when she did this activity with her class, she broke up the Explore section into three stations in the morning and three in the afternoon. She explained that the children were in groups of three or four at each station. Because she broke up the activity, two groups did the same experiment at the same time but in different parts of the room. When Hannah implemented the “Learn with Magnets” learning cycle, she chose to take two days to do the activities.

Reflective Journals

During her implementation of the “Changing Properties” learning cycle, Hannah wrote a journal entry about her experiences. Her journal began by explaining that, “the hands on activities were great!” She expressed that she “liked the 5Es [and]…made [her] so much more relaxed about having students dive in and then discuss what they discovered.” She also explained that the student created definitions were “just a natural extension.” Hannah expressed her goal “is always to have everyone engaged and interested.” Her class had some disagreements about their findings and she talked about how they could see who had the correct results through experiments and reference materials.

After her first experience, she wrote that the strengths of the 5Es included the engagement of students and the students as the recorders of information. Hannah “love[d] the group work,” as it required her students to “share and take turns.” The challenges she had using the learning cycle included the amount of preparation: “I need lots of prep time to work on my questioning techniques and content knowledge. The whole cycle was successful. I need practice leading discussions at the end.” She also mentioned it was difficult to have a large amount of time to complete the learning cycle. When discussing her perceptions of science, she wrote that
they had not changed, though “[she] can just implement a lesson better because she just ha[s] a format now to follow.” The 5E learning cycle format was similar to what she uses in language arts and math. When writing about the literature used, she wrote, “The book Pancakes, Pancakes by Eric Carle was perfect and I really liked using it at the end of the experiments when they had some knowledge to bring to the table.” Hannah concluded expressing her anticipation of using the 5E learning cycles in the fall “when things are not so crazy with end of the year activities and stresses!”

During her second learning cycle “Learn with Magnets,” Hannah took very careful notes about her experiences throughout each part of the cycle. She wrote about her instructions given to students in the Engage part that supplemented the teacher instruction sheet provided. In the Explore, she explained that the class discussed “discrepancies” like the staple pushed in the bulletin board and a loose staple. The class developed a hypothesis about “what sticks” and then modified it slightly in the Explain portion after reading the book. Though the materials were new in the Elaborate portions, Hannah explained, “There were no surprises to groups I listened in on, but many confirmations.” Finally in the Evaluate portion, Hannah assessed her students the following day in groups of two and three through the performance assessment provided in the learning cycle.

After the 5E learning cycle on magnets was completed, Hannah took the time to write her reflections down and shared them with the researchers. She expressed a like for the “flow” of the 5E model because the students were engaged. She wrote she “only thought about [science] at a deeper level when listening to the students’ hypotheses about kinds of magnetic metals.” The use of the magnet through water, plastic, and glass were also new experiences for Hannah. She wrote that the activity deepened her level of understanding of the science content because “[she]’d never thought or even wondered WHY iron is magnetic! (emphasis original)” After the 5E learning cycle, Hannah was left with questions about how “atoms? or molecules?” line up inside a solid object. She had asked her husband about this but still did not understand. Hannah wrote, “I love teaching science this way. I have a hard time finding time to devote to lesson writing and gathering materials. So I truly appreciate this opportunity to use a great lesson.” Finally in reference to using children’s literature to teach science, Hannah wrote that “anytime you can add a book always helps!” She contrasted this to the “dry textbook” and also included the need to read a book several times for “deeper understanding.”
**Particulate Nature of Matter Interview**

Hannah first participated in the PNM interview in May 2007 and again in December 2007 after implementing her two 5E learning cycles. When Hannah was asked to give explanations about the particulate level in question one, she explained in the pre-interview that a solid has particles that are tightly packed, but with some space. She related this to reactions that take place where these connections between the particles are changed. Because of this change, she decided there must be space for these new connections to be made. She mentioned that this space could be changed by energy. In the post-interview, Hannah connected the particulate to solids, liquids, and gases. She said particles are closer in a solid in comparison to a liquid, and particles in a gas are further apart than in a liquid. Hannah believed that particles that are cooled are closer together than particles that are heated. Finally, during the post-interview, Hannah discussed how the particles in magnets line up. These conceptions are shown in Figure 32.

![Diagram showing conceptions of particles for solids, liquids, and gases](image)

**Figure 32.** PNM Question 1 for Hannah.

For question two, Hannah felt that water from the outside air is condensed because the glass is colder than the air. In the post-interview, she elaborated on this idea by including a particulate explanation. She explained that the particles are closer in water than the particles in the gas. Further, for the water to condense on the glass, there must be water in the air. These conceptions are shown in Figure 33.
Question three, which asked what the mass would be of 1 pound of salt dissolved in 20 pounds of water, caused some confusion for Hannah in both interviews. During the pre-interview, she decided to use the term mass to describe her answer due to the term being in the question. She said that she was confident that the salt had mass; therefore, the mass of water and salt together would be greater than 20 pounds. In the post-interview, Hannah decided she was not comfortable using the terms mass or weight, however, after a conversation about them, she decided to used the phrase “amount of matter” to describe the concept. She admitted that she did not know the difference between mass and weight in the second interview, even though, after the pre-interview, she had discussed the concepts with her husband. She said that the amount of matter would stay the same because the salt did not go away. Hannah also discussed what it meant to “dissolve salt in water.” She explained that water and particles of salt come together to form new bonds during the dissolving process. She understood that not everything dissolves, specifically citing a rock as an example. Hannah’s conceptions of dissolving salt in water are shown in Figure 34.

Question four prompted a short explanation for Hannah as she said “they” (the water molecules) are further apart in the air but are still the same size. In the post-interview, she explained that “they” would be further apart, leading to fewer in the magnified view as a gas. In both instances, she drew the water molecules the same way they appear in the given view, but with fewer in the view. Hannah’s conceptions of evaporated water are shown in Figure 35.
Finally for question five, Hannah explained in the pre-interview that heating causes faster movement in a larger space. In the post-interview, she included the term particles. She explained that the distance between the particles expands when heated, but the particles themselves do not expand. These conceptions are shown in Figure 36.

Figure 36. PNM Question 5 for Hannah.
Use of Particulate Theory in Explanations

During Hannah’s PNM interviews, she used the particulate language in several instances, as shown in Table 13. During the pre-interview, Hannah explained in terms of “atoms or particles” for question one. In her post-interview, Hannah used “particles” to explain questions one, two, three, and five.

Table 13. Hannah’s use of the particulate theory.

<table>
<thead>
<tr>
<th>Question</th>
<th>Pre-Interview</th>
<th>Post-Interview</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>2</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>3</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

Uncertainty with PNM as shown in Explanations

Hannah expressed uncertainty in one instance in the pre-interview. Table 14 shows Hannah’s instance of expressed uncertainty throughout her interviews.

Table 14. Uncertainty in the PNM Explanations for Hannah.

<table>
<thead>
<tr>
<th>Question</th>
<th>Pre-Interview</th>
<th>Post-Interview</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

During the pre-interview, Hannah explained her answer to question four by asking a question: “Wouldn’t it show that only these would be further apart?” In the post-interview, Hannah said in her response to question three, “Aren’t the particles in the salt attaching to the water and forming different bonds?” Then in the pre- and post-interviews for question three, Hannah expressed not understanding the question due to confusion with the concepts of mass and weight, but then once her questions were answered, she did not answer with uncertainty. During the pre-interview, she chose the term mass and then answered without uncertainty. In the post-interview, she chose to use “amount of matter” in her explanation and then again gave her answer without uncertainty.
Science Teaching Efficacy Beliefs Instrument

Hannah participated in the STEBI assessment as a pre-test on May 7, 2007 prior to implementing her first 5E learning cycle. She also participated in the assessment as a post-test on December 18, 2007 after she completed her second learning cycle experience. The scores of her tests are shown in Table 15 for the two scales and the overall score.

Table 15. STEBI results for Hannah.

<table>
<thead>
<tr>
<th></th>
<th>PSTEBS</th>
<th>STOES</th>
<th>Overall Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Test</td>
<td>51</td>
<td>46</td>
<td>97</td>
</tr>
<tr>
<td>Post-Test</td>
<td>48</td>
<td>47</td>
<td>95</td>
</tr>
</tbody>
</table>

The data from Hannah’s responses show that her overall score dropped by 2 points between the pre- and post-tests. Her PSTEBS decreased by 3 points, whereas the STOES increased by 1 point. Figure 37 and Figure 38 present data on the individual questions within each scale, the PSTEBS and the STOES respectively. The increase of one point found for the STOES was contributed by only one variance in responses to number ten.

Figure 37. Pre- and Post-PSTEBS Individual Question Scores for Hannah.
Pedagogy of Science Inquiry Teaching Test

Hannah also took part in the POSITT, first on June 4, 2007 and then after the two 5E learning cycles on December 18, 2007. Her answers to the multiple-choice part of the vignette and the score she received for that answer are shown for each vignette in Table 16. Hannah’s responses to the “why” question are shown in the concept maps in Figures 39-44.

Table 16. POSITT multiple-choice responses for Hannah.

<table>
<thead>
<tr>
<th>Vignette</th>
<th>Pre-Test Answer</th>
<th>Pre-Test Score</th>
<th>Post-Test Answer</th>
<th>Post-Test Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C</td>
<td>1</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>1</td>
<td>B</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>B</td>
<td>1</td>
<td>B</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>A and B</td>
<td>0.5</td>
<td>B</td>
<td>1</td>
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<tr>
<td>5</td>
<td>B</td>
<td>1</td>
<td>A</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>B</td>
<td>1</td>
<td>B</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>5.5</td>
<td></td>
<td>5</td>
</tr>
</tbody>
</table>

For vignette one, Hannah chose multiple-choice option C for both the pre- and the post-tests, which indicated that Mr. Lowe “is not off to a good start.” Her explanations to this
question were framed in terms of what the students needed. In the pre-test, she described “the perfect way”: the students needed to make a connection before learning the different parts of the fish. Therefore, Hannah provided an example of a connection where students are asked, “If you lived underwater, what would you need? What would be different on your body?” In the post-test, Hannah thought that the vocabulary would not have meaning to the students without time for them to think and investigate the movement of a fish. A concept map of these conceptions is shown in Figure 39.

Hannah responded to vignette two with letter B and explained why she believed Teacher Betty employed the best approaches for achieving the desired goals. In the pre-test, Hannah believed that this approach allowed students to have some freedom to explore and observe. Students were also not reading from the textbook. In the post-test, she felt that this approach was better than option C because she liked that the exploration had a purpose. She understood the “free play” would happen anyway. The concept map for this vignette is shown in Figure 40.

Hannah selected letter B as her answer for vignette three both in the pre- and post-tests, using comparisons with scientific investigations as her justification. In the pre-test, Hannah explained in great depth why she thought Ms. Lefevre should do this option for her students’ investigation of the earthworm. Hannah described scientific investigations as including studying, synthesizing, and determining if data is good. The students do this determination through looking at the literature and repeating experiments; “it’s for the kids to decide why or what’s going on.” Hannah responded simply in the post-test that “[she thought] this [was] the

![Figure 39. POSITT vignette 1 for Hannah.](image-url)
answer that [was] most true to what happens in science in the real world.” Figure 41 shows the concept map for vignette three.

![Concept Map](image)

**Figure 40.** POSITT vignette 2 for Hannah.

![Concept Map](image)

**Figure 41.** POSITT vignette 3 for Hannah.

In the pre-test of vignette four, Hannah chose an answer between A and B, because she was not satisfied with either one. She did think that “taking them out to see the real thing instead of just telling them what they are looking at” was a good way for Ms. Jansen to start the lesson. Hannah believed though that it would be better if she had asked the students their ideas rather than explaining the answer right away. In the post-interview, Hannah chose option B for the same reasons. She explained, “It would have been better by letting them hypothesis (sic) what was going on before telling them.” Hannah also suggested that the students discuss this in small
groups and present their ideas to the class. Figure 42 contains the concept map for Hannah’s vignette four.

After reading vignette five in the both the pre- and post-test, Hannah expressed she thought this was better than vignette four. In the pre-interview she chose option B explaining that this allowed students to change the position of the flashlight and play in comparison to just looking at the moon. In the post-interview, she came to an opposite conclusion when she chose multiple-choice option A, Ms. Chavez was not off to a good start. Hannah’s alternative was for students to observe the real thing, make a hypothesis, and then do Ms. Chavez’s activity. This would allow the students to review and even modify the hypothesis they made at the beginning of the activity. A concept map for vignette five is shown in Figure 43.

![Concept Map](image)

**Figure 42.** POSITT vignette 4 for Hannah.

Hannah chose letter B for vignette six for both the pre- and post-tests. In the pre-test, Hannah believed that all students’ ideas should be considered and explored to determine if they are correct. This process is done through structured investigations and accomplished by the students on their own. In the post-test, Hannah contrasted option B to students being told they are wrong. Being told you are wrong provides no “connection” or “hook” for students to remember, and therefore, students may not understand why they are wrong. Instead they simply have to remember a fact. The concept map for vignette six is found in Figure 44.
Analysis

Hannah’s experiences in implementing the 5E learning cycles have been told, but these findings will now be analyzed in order to find its meaning in relationship to the theoretical framework of Novak’s Theory of Human Constructivism and the research questions.

Pedagogy of Science Inquiry Teaching Test

Hannah scored a 5.5 out of 6 on the pre-POSITT. Her loss of 0.5 was due to her response to question four where she did not choose A or B, rather created her own response that she
believed had a higher level of inquiry. Hannah desired to “tak[e] them out to see the real thing” like Ms. Jansen did, so she believed that was a good start to the lesson, but then like option “B” indicated, Hannah believed it would have been a better start to inquiry if she had asked the students their ideas rather than explaining the answer right away. On the post-POSITT, Hannah scored 5 out of 6. Her loss of 1 was due to her response of “A” to question four rather than the correct response “B.” Though Hannah believe Ms. Chavez’s lesson was better than Ms. Jansen’s approach, Hannah was still not satisfied with the provided scenario. Hannah provided an alternative lesson where students observe the real thing first, then make a hypothesis, and afterwards do Ms. Chavez’s model activity. In conclusion, though Hannah’s answers to vignette four on the pre-test and vignette five on the post-test were not the responses desired on the multiple choice portion, she did portray high standards for the inquiry process within her responses to the second tier of the vignettes.

Pedagogical Content Knowledge of Inquiry Science

Hannah provided answers on the POSITT that showed high standards for inquiry in both the pre- and post-tests. She desired to give her students opportunities to explore concepts and see the real thing. Hannah was not willing to settle for what was provided in the vignettes.

Hannah’s PCK of teaching science through inquiry was then compared to her actual experiences with inquiry in her classroom. Her experiences teaching science with the 5E learning cycles were positive. She expressed feeling more comfortable in allowing the students freedom to explore with the 5E structure. Hannah explained that she required time to improve her questioning and believed that she needed more practice leading the discussion in order to guide her students learning more effectively. She understood the intricacy of teaching science through inquiry, and this also portrayed she was thinking more deeply about the science content. This also conveyed Hannah’s understanding of the importance of the questioning within the inquiry process. She emphasized the importance of student thinking within inquiry during her post-interview, and expressed that she did think that “[students] have a deeper understanding of what it means instead of somebody than just telling them.” Hannah also reflected on the processes of thinking for her students. She saw inquiry as a method for helping her students be conscious of their thinking, and Hannah herself became more appreciative of the process her students were going through to learn. Hannah saw the importance of providing students the
opportunity to use this thinking to elaborate their newly formed conceptions. Finally, Hannah began to make the connection between the positive impacts on student learning when inquiry was used across all subjects. Because students become metacognitive during inquiry, Hannah said, “Once the kids have the opportunity to do [inquiry] everywhere, they approach learning differently.” Therefore, Hannah’s knowledge of inquiry was well connected to her actual practice, and she also desired to continue improving her abilities to teach science through inquiry.

Science Teaching Efficacy Beliefs Instrument

Hannah’s overall STEBI score decreased during the course of the research study from 97 in the pre-test to 95 in the post-test. This decrease was attributed to Hannah’s PSTEBS score, which decreased from 51 to 48 (her STOES increased from 46 to 47). When looking at the average scores of individual questions in Table 17, Hannah’s PSTEBS average was slightly greater than the STOES in the pre-test but in the post-test, less than the STOES.

Table 17. Hannah's average score of individual questions.

<table>
<thead>
<tr>
<th></th>
<th>PSTEBS</th>
<th>STOES</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Test</td>
<td>3.92</td>
<td>3.83</td>
<td>3.88</td>
</tr>
<tr>
<td>Post-Test</td>
<td>3.69</td>
<td>3.92</td>
<td>3.80</td>
</tr>
</tbody>
</table>

Within the PSTEBS, there was change in three responses. Question five had an increase of 1, but questions three and six each decreased by 2. Question three stated, “Even when I try very hard, I don't teach science as well as I do most subjects,” and Hannah’s responses transitioned from disagree to agree. Question six said, “I am not very effective in monitoring science experiments,” and Hannah disagreed to this question in the pre-test but agreed in the post-test. In the STOES, Hannah’s increase in score by 1 was attributed to an increase in question ten, which was the only question Hannah’s response did not receive 4, but in the pre-test 2 and post-test 3. Question ten states, “The low science achievement of some students cannot generally be blamed on their teachers,” and Hannah’s response transitioned from disagree to uncertain.
Self-Efficacy of Teaching Science

Hannah’s teacher efficacy decreased throughout the project and was due to her PSTEBS score, as Hannah’s score on the STOES increased slightly with a great deal of consistency in her responses. Hannah’s reflections on her 5E learning cycle experiences provided important insight into her decreased self-efficacy. Hannah explained, “I need lots of prep time to work on my questioning techniques and content knowledge.” She did not feel confident in teaching science as she had previously due to her requirement to spend time practicing teaching science through inquiry.

Particulate Nature of Matter

Through Hannah’s involvement in the PNM interview, the researchers were provided the opportunity to find meaning in what Hannah “thinks.” This meaning was found through analyzing Hannah’s conceptions in the same way as Aubrey and Janet’s were analyzed.

Correctness of Explanations

When Hannah was asked to give explanations about the her particulate level conceptions for the solid, liquid, and gas particles cited in question one, she explained correctly in the pre-interview that a solid has particles that are tightly packed, but with some space. Interestingly, she related this to chemical reactions. She discussed that connections between particles were changed requiring space for these new connections to be made. As she related this to a solid, this was incorrect due to reactions occurring at the surface of the solid.63 Hannah’s conception that this space could be changed by energy was correct. In the post-interview, Hannah related the particulate to solids, liquids, and gases. She said inaccurately that particles are closer in a solid in comparison to a liquid, and accurately that particles in a gas are further apart than a liquid.14 Hannah’s conceptions were even further from water, the most commonly used substance in the elementary grades, where liquid water is actually more dense than water as a solid.63 She Hannah also discussed the effects of heat in the post-interview, as she did energy in the pre-interview. In the post-interview she was more specific by explaining the difference between particle space when cooled and heated. Finally, Hannah connected her understanding of the particulate nature of matter to her experience with the 5E learning cycle on magnets. Hannah discussed how the “particles” in magnets line-up. Interestingly, Hannah drew dashes for
particles in her drawing of the magnet. Hannah made the connection between the magnet and the particulate, though she did not mention magnetism being caused by electrons or their movement, as stated by Serway and Jewett. Instead Hannah described it simply as “particles” that “line-up.” Therefore, it is unknown if Hannah had the correct conceptions of a magnet in this instance.

For question two, Hannah described that water from the outside air is condensed because the glass is colder than the air. This conception employed the verb “to condense” in order explain the appearance of the water. In the post-interview Hannah’s use of the space between particles in a liquid and in a gas was consistent with Harrison and Treagust.

In both the pre- and post-interview for question three, Hannah required a discussion of the difference between mass and weight because she did not understand the difference between the two. Prior to answering the question, she wanted to be certain of what she was going to say. For the pre-test, Hannah responded that the “mass” would be greater than 20 pounds. While this is partially correct, since 21 pounds is greater than 20 pounds, Hannah’s response was not fully correct, but she chose not to be more specific than this. Hannah’s responses combined Mulford’s multiple-choice options “c,” “d,” and “e.” Once Hannah decided to use the term “amount of matter” in place of mass in the post-interview, she was able to explain that the amount of matter would remain the same as what the salt and water were separately. Hannah did not place a specific number on this. Her response did provide the understanding that “matter” is conserved during the dissolving process. Another interesting conception provided by Hannah was that she explained that new bonds formed during the dissolving process. While Hannah was correct that bonds may be broken during the dissolution process, no new bonds are created. Instead of new bonds being formed, the sodium and chloride ions dissociate in the water with ion-dipole forces between the ions and the water.

Hannah’s explanations and drawings for question four during both interviews were correct. Her drawings strongly resembled Mulford’s correct option “e.” In the pre-interview she correctly explained “they” are further apart in the air, but are still the same size. In the post-interview, she explained “they” would be further apart, hence causing fewer in the magnified view as a gas.

Finally, Hannah’s explanations to question five remained consistent as letter “A.” This showed Hannah did not hold the misconception Harrison and Treagust cited “that particles
expand and contract [in order] to explain the expansion and contraction seen at the macroscopic level.” Hannah explained in the pre-interview that heating causes faster movement and a larger space. In the post-interview, she included the term particles and that they have a distance that expands but that the particles themselves do not expand.

Changes in Conceptions

Hannah’s conceptions throughout the project did change, but as Hannah elaborated on her conceptions, regressions were also found. In question one, Hannah, without being prompted, elaborated correctly that a gas was further apart than a liquid and a solid. The comment about the space between particles in a solid being required for a chemical reaction was absent from the post-interview so it is unknown if this conception remained. In question two, Hannah had the correct conceptions in both the pre- and post-interviews, and her conception did increase as she correctly related the macroscopic to the particulate through her discussion of the space between particles. Hannah’s conception about the “amount of matter” remaining the same between the salt and water in question three was an improvement in understanding as Hannah was willing to be more specific in her answer. However, she did not provide an actual mass to her conception, so it was unknown if the same amount of matter had the same mass to her. Hannah’s regression was found in question one as she elaborated her knowledge of the particulate nature of matter to solids and liquids, where she made errors in her conceptions.

Use of the Particulate Theory in Explanations

Hannah utilized the particulate theory in several of the interview questions and had an increase in occurrences in the post-interview. These occurrences, along with whether or not the terms were used correctly, are shown in Table 18. During the pre-interview, Hannah used the particulate to answer question one only. Her use was correct as she explained that during reactions, particles or atoms connect to things differently. This was subsequently correlated incorrectly to space. During the post-interview, Hannah used the particulate in all but one question, specifically question four. Hannah used the term particles to describe their space and orientation in question one, but did not correctly explain that space and orientation. In question two on condensation, Hannah used the term particles correctly to describe the difference in the space of liquid water on the glass and the water in the air. In question three, Hannah used the
term particles again to incorrectly describe that the salt forms different bonds with the water
during the dissolving process. Finally in question five, Hannah used the term particles to
correctly describe what happens during the heating of a liquid to a gas.

<table>
<thead>
<tr>
<th>Question</th>
<th>Pre-Interview</th>
<th>Post-Interview</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>2</td>
<td>✓</td>
<td>✓</td>
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<td>3</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>4</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>5</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

**Uncertainty with PNM as shown in Explanations**

Hannah was uncertain in the explanations she provided in only two instances (see Table 14). She did not use terms like “guess,” but answered two of the interview questions with questions. Hannah’s uncertainty was found once in each interview. The occurrence in her pre-interview occurred in the direct response to question three. The occurrence within the post-interview happened while Hannah was relating the “particles in the salt” dissolving in water to bonding.

**Knowledge of the Particulate Nature of Matter**

Hannah answered the questions well during the particulate nature of matter interview, though at times while providing her explanations to the particulate concepts, she was not able to provide correct details. Throughout her interview, Hannah sought to make connection between her conceptions and the things she was studying. Throughout her interviews, Hannah showed consistency in her responses to the PNM questions. Hannah’s responses in the post-interview to question one were consistent with questions two, four, and five and the literature. Hannah’s use of the space between particles in a liquid and particles in a gas was consistent with her response to question one and Harrison and Treagust. Her responses were also consistent between questions two and four. Hannah was aware that the water that condensed on the glass was from the air, and in question four, depicted water evaporating into the air without a reaction occurring.
Consistency between answers was also found in questions one and five. Harrison and Treagust paired the misconception that matter is continuous with the misconception that “that particles expand and contract.” Hannah did not convey either of these misconceptions.

Through the incorporation of the 5E learning cycles into her classroom, Hannah was required to think more deeply about the science content. She had new experiences in “Learn with Magnets” and really became interested in magnets at the particulate level. Hannah had the ability to discuss macroscopic phenomena of a magnet in terms of the particulate nature of matter; however, her exact conceptions were not clear based upon her responses provided during the PNM interview. During the same interview, Hannah called what are actually electrons, “particles,” but in her journal expressed uncertainty about whether the things that “line-up” were “molecules” or “atoms.” She admitted that she had never thought about why iron was magnetic. Within her classroom, Hannah also desired to take students further into the science content, but sometimes felt it was too difficult and complex for her students. She said, “It is hard for me sometimes to bring stuff down low enough.” This could be due in part to Hannah having difficulty understanding the particulate at times herself (for example, the magnet) and also due to this being her second year in the first grade and had taught higher elementary grades prior to this.

**Conclusion**

As a teacher with 21 years of experience in a wide variety of positions within the district, from the beginning of the project, Hannah expressed, “I am comfortable with doing [science]. I am not comfortable in how I am doing it because…it’s not a priority. I don’t spend the amount of time to do it as well as…I want to do it.” The aspect Hannah disliked about teaching science was the lack of time she had for planning. Hannah conveyed at the end of the project that she felt her confidence in teaching science in the first grade had increased from the year before because this was her second year teaching that particular grade level.

The findings of Hannah’s case based on Novak’s Theory of Human Constructivism include that Hannah had knowledge of inquiry practices and this knowledge was well connected to the psychomotor domain as she was able to implement this knowledge during the 5E learning cycles. She was confident in her ability to teach science but did decrease in this confidence as evidenced by her STEBI scores. This could be connected to her cognitive domain due to her knowledge of science. Hannah had a grasp of the particulate nature of matter and how it relates
to the macroscopic, however, at times she realized her limited knowledge. For instance, during her response to question three in her post-PNM interview, Hannah explained how salt dissolves in water and then expressed, “So that’s about as much as I can understand that.” Also, Hannah was not satisfied with “guessing” during her interviews. Therefore, Hannah displayed connections between the three domains of learning.
Chapter 7: An Analysis Across the Cases

Introduction

This chapter uses the theoretical framework that guided this inquiry, and its core construct of meaningful learning, to conduct a cross case analysis. Data and themes were analyzed across the individual cases in an effort to find the meanings of the teachers’ overall experiences within the school district and to present possible directions for future research.

5E Learning Cycles

The two 5E learning cycles that each teacher chose to implement into their classrooms constituted the psychomotor domain of Novak’s Theory of Human Constructivism. A great deal was learned about their experiences from the teachers’ journals and their post-interviews. The teachers were very positive about their experiences teaching with the 5E learning cycles, but Aubrey did have a difficult experience with her second one due to her lack of experience with that particular standard. From the teachers’ journals and interviews, several themes emerged about the teachers and their 5E learning cycle experiences.

Teachers discussed the level of knowledge students had before the learning cycle. For Aubrey, her first learning cycle on “Sorting” went very well, and she believed this was due in part to her class working through a unit on the concept of sorting for some time before the 5E learning cycle. When Aubrey discussed “Materials Classification,” she realized that many of the difficulties she encountered were due to her and her students not having previous experience with that specific standard. Janet also discussed students’ prior knowledge when talking about her experiences during the “Learn with Magnets” learning cycle. Janet would have rather had her students read the book about magnets prior to the learning cycle, which suggested her desire for students to have heard the Explain before they were Engaged and did the Explore.

Teachers made modifications to the 5E learning cycles prior to the implementation. Janet and Hannah both chose to make modifications to one of their learning cycles, specifically the “Changing Properties” learning cycle. Hannah’s modification was to have three of the stations in the morning and the other three stations in the afternoon. She thought that this worked better for her classroom. In comparison, Janet’s modifications took the form of eliminating the stations and instead adding demonstrations and full class activities. She explained this was for
“management” purposes due to her class’ behavioral difficulties. Aubrey did not specifically reference making changes to the learning cycles she implemented.

Teachers’ knowledge and understanding was challenged and increased through implementation of the 5E learning cycles. Aubrey’s perceived knowledge deficiencies with how to classify materials led her to have conversations with other teachers and the researcher about classification. The learning cycles also caused Hannah to think more deeply about magnets. This showed evidence that the teachers learned science through teaching by inquiry, a fact cited by the National Research Council as one of three ways for teachers to learn science content.

Finally, the three teachers discussed time. Each teacher suggested spreading out the 5E learning cycles over more than one day, and Aubrey expressed the desire for an even longer period of time than a couple days. Each teacher also had expressed from the beginning of the project that they did not have enough time to teach science.

**5E Learning Cycles and Human Constructivism**

The psychomotor and cognitive domains within meaningful learning had very different outcomes for the individual teachers in their 5E learning cycle experiences and journal reflections. Though they believed their experiences to be positive, their actions in the classroom did not always reflect their knowledge of inquiry. Aubrey and Janet’s desires for students to have prior knowledge of the concepts could be in opposition to the nature of scientific inquiry. However, this does align with Novak’s Theory of Human Constructivism because as stated previously, the first of the three conditions for meaningful learning is “a student must have some relevant prior knowledge to which the new information can be related in a non-arbitrary manner.” The modifications that Janet made to the “Changing Properties” 5E learning cycle showed her lack of confidence in her students to behave well and her lack of confidence in herself to manage the students to do the scientific inquiry. This became a hindrance for Janet in executing her knowledge of the inquiry. The 5E learning cycles caused Aubrey and Hannah to explore the limits of their cognitive domain as the learning cycles made them think more deeply about the content they were teaching. The teachers’ struggle to find the time to incorporate science into their classrooms was then paired with the teachers’ realization that scientific inquiry was a process and took time for students to grasp the concepts.
Pedagogical Content Knowledge in Teaching Science through Inquiry

The POSITT assessed the teachers’ knowledge of teaching science through inquiry, and as shown Figure 45, there was not much change between the pre- versus post-POSITT administration. All three teachers brought to the project some knowledge of inquiry, which they gained from their experiences with an inquiry-based math curriculum. The reasons for less than perfect scores included providing no response to vignettes, or in the case of Hannah, incorrect or partially incorrect multiple-choice responses. It is important to note that both of Hannah’s incorrect multiple-choice response were accompanied by responses to the second tier that were at least as good as the ones the authors provided.

![Figure 45. POSITT multiple-choice scores of Aubrey, Janet, and Hannah](image)

When looking across the three cases, it was interesting that Aubrey, Janet, and Hannah used similar concepts to discuss inquiry. Each teacher discussed how important it was for students to do things “on their own” versus the teacher “telling the students” what they should do. There was also a great deal of emphasis placed on providing opportunities for students to view “the real thing” being studied, for example, studying a real fish when trying to determine what the various anatomical parts did or looking at the moon when talking about the different phases. Janet was the only teacher who used the 5E learning cycle as a tool for describing inquiry. Overall, the teachers were able to describe inquiry and performed well on the POSITT.
Pedagogical Content Knowledge of Inquiry Science and Human Constructivism

The teachers expressed that they had positive experiences teaching with the 5E learning cycles. According to the POSITT results, the teachers had a significant knowledge of inquiry from the start and did make gains in this understanding during the project. Aubrey’s descriptions of inquiry became more specific, Janet applied the 5E learning cycle as an analysis for inquiry, and Hannah conveyed that she was not satisfied with the inquiry lessons provided within the vignettes. In the cases of Aubrey and Janet, however, this knowledge of inquiry was not always put into practice. For example, Aubrey desired to do a unit prior to the 5E learning cycle and Janet expressed the desire to read the literature on magnets prior to the Engage and Explore. Like Mazur explained with learning physics, many students have dual knowledge sources: knowledge that is used in their physics classes and knowledge that used in their everyday lives. In many instances, these sources of knowledge are disconnected and so too would it seem is the knowledge Aubrey and Janet possess about teaching science through inquiry. They possess knowledge of proper inquiry practices in the cognitive domain; however, this knowledge is disconnected at times from the psychomotor domain and their actual practice.

Self-Efficacy

In order to compare the teachers’ beliefs about teaching science, the STEBI results were analyzed. The data for the two scales, the Personal Science Teaching Belief Scale and the Science Teaching Outcome Expectancy Scale, and the overall STEBI results are shown in Table 19. Overall, Janet’s score indicated an increase in efficacy, while both Aubrey and Hannah’s indicated a decline in efficacy. Janet’s overall score increase was attributed to an increase in both the PSTEBS and the STOES. For Aubrey and Hannah, their scores increased in the STOES, but declined in the PSTEBS. Hannah had the largest drop in score between a pre- and post-test scale; this occurred within the PSTEBS.

Table 19. Comparison of Aubrey, Janet, and Hannah's STEBI scores.

<table>
<thead>
<tr>
<th></th>
<th>Aubrey</th>
<th></th>
<th>Janet</th>
<th></th>
<th>Hannah</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-Test</td>
<td>Post-Test</td>
<td>Pre-Test</td>
<td>Post-Test</td>
<td>Pre-Test</td>
</tr>
<tr>
<td>PSTEBS</td>
<td>45</td>
<td>43</td>
<td>48</td>
<td>52</td>
<td>51</td>
</tr>
<tr>
<td>STOES</td>
<td>46</td>
<td>47</td>
<td>44</td>
<td>46</td>
<td>46</td>
</tr>
<tr>
<td>Overall Score</td>
<td>91</td>
<td>90</td>
<td>92</td>
<td>98</td>
<td>97</td>
</tr>
</tbody>
</table>
An interesting finding of the STEBI pre- and post-tests was that the teachers all scored within a range of 90 to 98, whereas the possible range of STEBI scores is between 25 and 125. There was little variation in the scores on individual scales, though the range was larger on the PSTEBS than the STOES, as can be seen in Figure 46.

![Figure 46. Comparison of the STEBI results for Aubrey, Janet, and Hannah.](image)

**Self-Efficacy and Human Constructivism**

When the three teachers were compared, their results on the STEBI were not always congruent with the results of their 5E learning cycle experiences and reflections. As the findings showed, Janet self-scored the most confident in the post-test and exhibited the greatest gains in efficacy over the course of the project. This gain in self-efficacy can be contrasted to Janet’s actual practice with modifications to the “Materials Classification” and her desire to read the literature first. Both Janet and Hannah’s responses varied on specific items, but otherwise remained consistent. Aubrey had the lowest overall efficacy score in both the pre- and post-tests, and her score slightly decreased between the two tests. In contrast to Janet and Hannah, her scores within each scale and between tests fluctuated in many instances portraying she was in flux about her self-efficacy. This was aligned to her difficulty with guiding students. It is
interesting to note that Janet and Hannah were both older than Aubrey, which could contribute to their consistency. Paradoxically, both Aubrey and Hannah expressed in post-interviews that their confidence in teaching science had increased; yet, their scores indicated otherwise. Hannah’s decline was attributed to her desire for more practice in questioning and in content knowledge. Finally, these three teachers were very different, but their scores were very close together (in the range of 90-98). Perhaps this can be attributed to the nature of the test where the teachers answered the questions based upon what they knew to be the correct answer rather than how they actually felt.

**Knowledge of the Particulate Nature of Matter**

**Correctness of Explanations**

When discussing particulate space in question one of the PNM interview, the three teachers conveyed both correct and incorrect conceptions. Aubrey and Hannah discussed correctly that there existed some space between particles in a solid within the pre-interview, but it was inconclusive if Janet held this conception due to her expressions of “really close together” and “little space.” Though prompting took place in the case of Janet, all three teachers discussed the difference in space between particles in a solid, liquid, and gas in the post-interview. Each teacher conveyed the misconception cited by Harrison and Treagust, which was in contrast to “spacing between solid-solid, liquid-liquid, and gas-gas particles is about 1:1:10.” In all three cases, the misconception was found in the ratio between solid-solid and liquid-liquid particles as they thought the solid-solid space would be less than the space for liquid-liquid. Furthermore, they made no indication of an understanding of the spacing between particles in liquid and solid water, which is actually opposite of the teachers conceptions and the substance used most in the elementary grades. Aubrey was the only teacher who explicitly said, “Matter is made up of individual particles,” and Hannah was the only teacher who discussed reactions and energy in her pre-interview and heat and magnets in her post-interview, which conveyed Hannah’s ability to think deeply about the science content and make connections to other concepts.

In their explanations to question two in both the pre- and post-interviews, each teacher explained that the water on the outside of the glass came from the air. This conception is correct, in contrast to Mulford’s multiple-choice option, which states, “The coldness causes oxygen and hydrogen from the air to combine on the glass forming water.” Each teacher also discussed the
cause of the water on the outside of the glass. Aubrey discussed this in terms of “the cold” and extended this in the post-interview to the cold “attract[ing]” the water. Janet explained that the water (or moisture in the post-interview) was “drawn” to the glass by the difference in temperature. She explained this difference was between the colder inside of the glass and warmer outside of the glass. Aubrey and Janet portrayed similar conceptions in the movement of water with the terms “attract” for Aubrey and “drawn” for Janet. Hannah discussed in her pre-interview that the “glass is colder than the air around it” and described that the water “cooled off” in the post-interview. When describing their answers, Aubrey used the noun “condensation,” Hannah used the verb “to condense,” and Janet did not use a form of this word. Janet instead used the nouns water and moisture and forms of the verb “to draw.” Hannah was the only teacher who discussed water as liquid and gas at the particulate level. It is interesting to note there was no mention of this in Chemical Concepts Inventory (CCI) options. Mulford’s correct option states, “Water vapor condenses from the air;” however the teachers did not use the term “vapor” to describe water in the air. This confirmed the methodological choice to interview the teachers about the particulate nature of matter.

Interview question three solicited a variety of responses in both the pre- and post-interviews. In the pre-interview, the teachers did not answer the question correctly. Aubrey chose an answer between 20 and 21 pounds, Janet chose 20 pounds, and Hannah chose greater than 20 pounds. Janet was the only teacher who placed a specific number to her response, while both Aubrey and Hannah’s responses contained ambiguity. For the post-interview, Aubrey and Janet selected the correct answer 21 pounds, which made use of the conservation of mass during dissolution. Hannah was not comfortable using the term mass and did not provide a numerical answer; however, she did provide the correct conception that the “amount of matter” stayed the same as the salt and water separately. Janet and Hannah took the time to explain their conceptions of the dissolving process. Janet discussed macroscopically that the “salt went into the water.” Hannah discussed the particulate correctly when she said bonds break in the dissolving process but incorrectly with the addition that new bonds form in the process. Another interesting occurrence was Aubrey’s comments about the “obvious” in relation to this question. Janet and Hannah did not express this sentiment of science being complex or not obvious. Finally, Hannah was the only teacher who expressed confusion with terms mass and weight.
The responses to question four consisted of only two options and the teachers’ conceptions either regressed or remained the same between the pre- and post-interviews. The two options included the correct conception where the water molecules spread apart, but remain intact (similar to option “e” from the CCI) or the incorrect conception with the water molecules breaking apart into monatomic oxygen and hydrogen (like option “d” from the CCI). Aubrey’s conception regressed from the correct, water remaining intact, to the incorrect of separate oxygen and hydrogen. Janet’s conceptions remained incorrect that the oxygen and hydrogen separate due to a need for something to change. Hannah’s conceptions also remained consistent. In Hannah’s case, her consistency was correct containing the conceptions of the water remaining intact like option “e.”

The responses to question five remained constant and correct for both Aubrey and Hannah, because in both cases, they chose the correct option A and avoided the common misconception cited by Harrison and Treagust 14 “that particles expand and contract [in order] to explain the expansion and contraction seen at the macroscopic level.” For Janet, an interesting distinction emerged during her pre-interview: in her mind, there was a difference between heating a liquid to a gas and a liquid evaporating. When heat was applied, Janet explained B as the correct response, though she did describe liquid evaporating like A. In the post-interview, Janet was the only teacher who used the macroscopic through a tea kettle analogy to deduce her answer. Unfortunately, the usefulness of this analogy was limited as she could not relate the tea kettle to the particles.

Changes in Conceptions

The three teachers exhibited improvements and regressions within their answers during the PNM interview. Improvements occurred in question one for all three teachers, as they explained the difference in space between particles in gas and particles in a solid and liquid. Question two showed improvements in only Hannah’s conceptions where she discussed her response in terms of the particulate nature of matter in the post-interview. Question three conveyed an increase in understanding for Aubrey and Janet as they both answered the correct answer of 21 pounds in the post-interview. In her post-interview, Hannah understood that the “amount of matter” remained constant between the salt and water, which was more specific than her answer of greater than 20 pounds provided in the post-interview; however, it was not
possible to determine whether Hannah believed that this conservation of matter resulted in a weight of 21 pounds for the salt water solution. No improvements were found for the teachers in their responses to question four. Then in question five, though not necessarily an improvement, Janet transitioned her incorrect conception of “B” to complete uncertainty.

Throughout the interviews, there existed fewer regressions within the teachers’ responses. All three teachers made errors in their explanations to question one when they explained there was a difference in the particulate space in solids and liquids. Questions two, three, and five had no regressions; however, in question four, Aubrey’s conception regressed from the correct answer with evaporated water molecules still intact to the separation of the hydrogen and oxygen into monatomic gases.

Use of the Particulate Theory in Explanations

Throughout the PNM interviews, Aubrey, Janet, and Hannah used the particulate theory within their explanations. Comparisons of these uses and whether or not they were correct are show in Table 20. In the pre-interview, each teacher used the particulate terms in only one instance; Aubrey in question five, Janet in question four, and Hannah in question one. It is notable that these instances were not within responses to either question two or three, which were phrased in macroscopic terms. In the post-interview, Aubrey had two instance of the particulate theory used, Janet remained the same at one, and Hannah increased to four. Hannah was the only teacher who used the particulate theory to respond to questions two and three. When Aubrey and Janet did not use the particulate to describe the macroscopic, this is consistent with Haidar’s and Abraham’s remark that “this shows that students seem to compartmentalize information,” in this case about the particulate nature of matter.

Table 20. Comparison of Aubrey, Janet, and Hannah’s use of the particulate theory.

<table>
<thead>
<tr>
<th></th>
<th>Aubrey</th>
<th></th>
<th>Janet</th>
<th></th>
<th>Hannah</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Question</strong></td>
<td><strong>Pre-Interview</strong></td>
<td><strong>Post-Interview</strong></td>
<td><strong>Pre-Interview</strong></td>
<td><strong>Post-Interview</strong></td>
<td><strong>Pre-Interview</strong></td>
</tr>
<tr>
<td><strong>1</strong></td>
<td>Use</td>
<td>Correct Use</td>
<td>Use</td>
<td>Correct Use</td>
<td>Use</td>
</tr>
<tr>
<td><strong>2</strong></td>
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<td><strong>3</strong></td>
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<td><strong>4</strong></td>
<td>√</td>
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<td>√</td>
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<td>√</td>
</tr>
<tr>
<td><strong>5</strong></td>
<td>√</td>
<td>√</td>
<td></td>
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</tbody>
</table>
Uncertainty with PNM as shown in Explanations

Aubrey, Janet, and Hannah each exhibited uncertainty within both the pre- and post-interview. As shown by Table 21, the number of occurrences was quite different among the three teachers. Hannah had the least occurrences of uncertainty in each interview, followed by Aubrey, and then Janet with the most.

Table 21. Comparison of Aubrey, Janet, and Hannah's uncertainty with the PNM.

<table>
<thead>
<tr>
<th>Question</th>
<th>Aubrey Pre-Interview</th>
<th>Aubrey Post-Interview</th>
<th>Janet Pre-Interview</th>
<th>Janet Post-Interview</th>
<th>Hannah Pre-Interview</th>
<th>Hannah Post-Interview</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>9</td>
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<td>6</td>
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<td>Total</td>
<td>5</td>
<td>6</td>
<td>17</td>
<td>24</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Particulate Nature of Matter and Human Constructivism

As teachers of elementary children, Aubrey, Janet, and Hannah focused on the macroscopic level in their science teaching, but as Gabel, Samuel, and Hunn explained, there is a need for elementary teachers to be “familiar with the particulate nature of matter in order to make sense of every day phenomena they encounter and teach children.” Each teacher did have some knowledge of the particulate nature of matter, and as can be seen through the analysis, Hannah’s content knowledge was the most conceptually sound. Hannah was able to use her correct conceptions consistently and also with little uncertainty. There were times she elaborated her conceptions with explanations that did not hold up to theory, for instance her conceptions that a chemical reaction occurred during the dissolution process. As with magnets, Hannah’s thoughts and actions conveyed that she was thinking about the concepts she was teaching at a deeper level. Hannah was the only teacher who made use of the particulate nature of matter to describe the macroscopic within the PNM interviews. Aubrey’s conceptions of the particulate nature of matter were not as strong as Hannah’s conceptions. Aubrey expressed more instances of uncertainty and also had inconsistencies within her responses. Also, in question four, Aubrey’s conceptions of evaporating water regressed during the course of the study. Janet’s knowledge of the PNM exhibited the least conceptual understanding and the most uncertainty. Janet did make some gains in conception and was able to think about the macroscopic at the particulate level to try to deduce the particulate. She reflected on her experiences dissolving salt
in water to respond correctly to question three in the post-PNM interview. Though this happened at different levels for each teacher, it was found that as the teachers’ conceptions were probed deeper, their understanding could not be elaborated upon or was elaborated upon incorrectly. For instance, both Aubrey and Janet had difficulty explaining “why” water condensed on the side of the glass of cold milk in question two. Another interesting occurrence was that Aubrey and Hannah both reflected upon their science knowledge and tried to learn more about what they did not know in the 5E learning cycles. Though Janet may have done this, it was not made visible to the researcher in either her interviews or journal entries. For Aubrey and Hannah, this reflection showed a merging of the cognitive and psychomotor domains within meaningful learning, but there was no evidence of this for Janet.

**Conclusion**

Aubrey, Janet, and Hannah chose to participate in this project and incorporated inquiry science lessons into their classrooms, which they explained was against the formidable time pressures they faced daily in their classrooms. None of the three teachers expressed a dislike for the actual teaching of science; however, each had her own reasons for not teaching science as much as she might have liked. Further, Aubrey, Janet, and Hannah also felt that language arts were their highest priority; Hannah also included math as a high priority in her curriculum. Despite the daunting challenges they faced, the three teachers were committed to teaching science, as exhibited when Janet said at the beginning of the project that, “[e]ven though I have a lot on my plate this time of the year, I am forcing myself to do [a 5E learning cycle] because science is important.”

Aubrey, Janet, and Hannah’s participation within the research project allowed the researcher insight to their experiences in teaching science through inquiry, specifically the aspects which promote meaningful learning for the teachers. As Novak12 explains, “Meaningful learning underlies the constructive integration of *thinking, feeling, and acting*, leading to human empowerment for commitment and responsibility.” For each teacher, there existed footholds that did not allow them to fully learn meaningfully. For Aubrey, her “thinking” about the PNM was not conceptually sound, which caused difficulty in the psychomotor domain during the implementation of the learning cycles. Aubrey increased in the psychomotor domain by teaching a standard she had never previously taught, which caused her to stretch herself within the
cognitive domain. A disconnect existed for Janet between her increased efficacy within the affective domain and her conceptual difficulties within the cognitive domain on the PNM and using her knowledge of inquiry within the psychomotor domain. Hannah had the most conceptually sound cognitive domain about the PNM, but her efficacy in the affective domain declined. Hannah’s connections between the cognitive and the affective domains developed over the course of the project as she realized she lacked some of the content knowledge required to understand the concepts she was teaching. Hannah did continue to feel the pressures to marginalize science, and at the end of the project, Hannah still felt science was not a priority. Learning is a continuous process, and it was obvious through the commitment to this research project that Aubrey, Janet, and Hannah are lifelong learners constantly seeking to improve their teaching.

Overall, the teachers exhibited many connections and also several disconnections across the domains of learning. It was found that especially for Aubrey and Janet there existed a disconnect between the cognitive domain and the psychomotor domain. They both had a strong understanding of good inquiry practices, but this did not always translate to practice within their classrooms. Within the cognitive and psychomotor domains, it was found that with prior knowledge of the PNM, teaching physical science through inquiry can uncover gaps in this knowledge. Aubrey and Hannah both exhibited this connection as they asked questions about the science content and revealed new ideas in science. Finally, the connections between the affective and cognitive domains were analyzed. It was found that the cognitive domain only influenced the affective domain if the cognitive domain was connected to the psychomotor domain. Janet had weak PNM knowledge, but her self-efficacy increased. This portrayed that Janet did not understand the need to have a deep knowledge of the content in order to teach science. Her cognitive and psychomotor domains were not connected in this way, and her affective domain was not connected to her cognitive domain. Hannah on the other hand did have some PNM knowledge, and her self-efficacy decreased as she realized her content knowledge needed to be increased.

**Future Research**

The conclusions presented in this study elicit the need for further research in the use of the 5E learning cycles as opportunities for meaningful learning for teachers. There are several
avenues this future research could take. These 5E learning cycles at present were modified by the teachers implementing them in this study. With the knowledge of the modifications developed and the reasons for these modifications, the researchers should critically analyze each of the existing 5E learning cycles to determine if such modifications are appropriate for other cycles. Further, it is important that additional 5E learning cycles are added to the collection to provide teachers with a comprehensive selection to choose from.

As discussed by Bretz in the *Nuts and Bolts of Chemical Education Research*, the research questions in this study required a qualitative research methodology in order to explore the relationships between inquiry teaching and the particulate nature of matter, self-efficacy, and pedagogical content knowledge. The findings from this qualitative study require further research for generalization, which, as discussed by Towns, can be accomplished through a sequential exploratory design where a quantitative study follows a qualitative study. Future research should study if the use of 5E learning cycles does increase teachers’ pedagogical content knowledge. Future research should focus on 5E learning cycles and if using them increases teachers’ knowledge of the particulate nature of matter. Finally, one of the more significant trends uncovered during the course of this research has been the disconnection between the cognitive and the affective domains in conjunction with a disconnect between the cognitive and psychomotor domains among the teachers in this study, i.e., the disconnect between the teachers’ content knowledge and their pedagogical knowledge. Meaningful learning can only be achieved when teachers make connections across the three domains. Future research should focus on teachers’ pedagogical content knowledge and their knowledge of the particulate nature of matter. Towns explained that the sequential exploratory design lends well to the development of an instrument. This research should focus on developing an instrument, like the POSITT, with cases teaching the Nature of Matter indicators in order to better study the connection between the cognitive and psychomotor domains.

**Statement of Reflection**

This qualitative research project was very meaningful for this researcher, and it is critical for her to reflect on her experiences.

I had prior knowledge of the particulate nature of matter, self-efficacy, and pedagogical content knowledge in teaching science through inquiry before the research began. By working with Aubrey, Janet, and Hannah, my conceptions of these constructs
have grown immensely. As a future high school chemistry educator, this research experience will impact my future classroom.

In order to conduct the PNM interviews, I was required to delve into the misconception literature on the PNM. This improved my understanding of matter at the particulate level, and the interview experience will prove useful in determining my future students’ misconceptions. I also understand the importance of the PNM and will focus my classroom there. The data collected during the PNM interviews also provided me with a greater understanding of the prior knowledge of my future students. If at the primary level, teachers hold misconceptions of the PNM and even do not teach all the standards required on the Nature of Matter, students may hold many misconceptions of the particulate level. This project has also been a springboard for a passion to work with the elementary and middle school teachers to bring unity among the school districts in my future. This will hopefully provide a community to discuss science concepts that are not fully understood.

Within the affective domain of learning, I have reflected greatly on my own feelings about teaching chemistry. I admit to being more confident in teaching some areas of chemistry over others. Therefore, through the knowledge I have gained in this project, I desire to remain metacognitive about my science teaching. I will realize where my self-efficacy is lower and seek support from other teachers in the content and teaching strategies for those particular concepts. I will not shy away from concepts on account of a lack of full understanding.

Pedagogically, I have grown in my understanding of inquiry through the process of creating and revising the 5E learning cycles. It has been further impressed upon me that “knowing is in the explaining.” I also understand that I am prone to the same inconsistencies of believing in inquiry and knowing about it, but then due to other pressures, making choices to not take the time to create an inquiry-based classroom. Also, by creating a community of teachers discussing science concepts as described above, this could be a difference in content being taught through inquiry, being taught without inquiry, or even not being taught at all.

This research project has provided me with countless opportunities to learn meaningfully. I have been challenged to remain in tune with my thinking, feeling, and acting and how they affect each other for my future classroom. These are invaluable lessons that will be carried through my career as a chemistry educator.
References


(33) Shulman, L. S. Educational Researcher 1986, 15, 4-14.


(43) Riggs, I. M.; Enochs, L. G. Science Education 1990, 74, 625-637.


Appendix A

National Science Education Standards

Physical Science: K-4

Properties of Objects and Materials

- Objects have many observable properties, including size, weight, shape, color, temperature, and the ability to react with other substances. Those properties can be measured using tools, such as rulers, balances, and thermometers.
- Objects are made of one or more materials, such as paper, wood, and metal. Objects can be described by the properties of the materials from which they are made, and those properties can be used to separate or sort a group of objects or materials.
- Materials can exist in different states--solid, liquid, and gas. Some common materials, such as water, can be changed from one state to another by heating or cooling.
Appendix B

Ohio Science Academic Content Standards

Kindergarten

Physical Science

Nature of Matter

1. Demonstrate that objects are made of parts (e.g., toys, chairs).
2. Examine and describe objects according to the materials that make up the object (e.g.,
   wood, metal, plastic and cloth).
3. Describe and sort objects by one or more properties (e.g., size, color and shape).

First Grade

Physical Science

Nature of Matter

1. Classify objects according to the materials they are made of and their physical properties.
2. Investigate that water can change from liquid to solid or solid to liquid.
3. Explore and observe that things can be done to materials to change their properties (e.g.,
   heating, freezing, mixing, cutting, wetting, dissolving, bending and exposing to light).
4. Explore changes that greatly change the properties of an object (e.g., burning paper) and
   changes that leave the properties largely unchanged (e.g., tearing paper).
Appendix C

Matrix Linking Science Trade Books to First Grade Standards

<table>
<thead>
<tr>
<th>ISBN</th>
<th>Title</th>
<th>Author</th>
<th>Physical</th>
<th>Life</th>
<th>Earth</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-688-17839-1</td>
<td>I Get Wet</td>
<td>Vicki Cobb</td>
<td>1.L.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-394-80075-3</td>
<td>Bartholomew and the Oobleck</td>
<td>Dr. Suess</td>
<td>1.L.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-590-87175-7</td>
<td>Red-Eyed Tree Frog</td>
<td>Joy Cowley</td>
<td>1.L.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-06-445111-9</td>
<td>Milk From Cow to Carton</td>
<td>Aliki</td>
<td>1.L.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-58430-034-5</td>
<td>Summer Sun Risin'</td>
<td>Nikola-Lisa</td>
<td>1.P.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-8050-1259-1</td>
<td>When Autumn Comes</td>
<td>Robert Maass</td>
<td>1.L.5</td>
<td>1.E.1</td>
<td></td>
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<tr>
<td>0-689-82919-1</td>
<td>Let's Try It Out In The Water</td>
<td>Seymour Simon, Nicole Fauteux</td>
<td>1.L.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-7398-4427-X</td>
<td>From Chick to Chicken</td>
<td>Jillian Powell</td>
<td>1.L.2</td>
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<tr>
<td>0-8225-4594-2</td>
<td>We Use Water</td>
<td>Robin Nelson</td>
<td>1.P.2</td>
<td>1.E.1</td>
<td></td>
</tr>
<tr>
<td>1-40345-157-5</td>
<td>The Sun</td>
<td>Patricia Whitehouse</td>
<td>1.P.8</td>
<td>1.E.2</td>
<td></td>
</tr>
<tr>
<td>1-57091-500-8</td>
<td>Birds Build Nests</td>
<td>Yvonne Winer</td>
<td>1.L.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-15-266197-2</td>
<td>Red Leaf, Yellow Leaf</td>
<td>Lois Ehlert</td>
<td>1.L.5</td>
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<td></td>
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<tr>
<td>0-15-216584-3</td>
<td>Pie in the Sky</td>
<td>Lois Ehlert</td>
<td>1.L.5</td>
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<tr>
<td>0-06-021054-0</td>
<td>Where Does the Garbage Go?</td>
<td>Paul Showers</td>
<td>1.P.1</td>
<td>1.E.2</td>
<td></td>
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Appendix D

**Sorting**
Based on *Sorting* by Henry Pluckrose
Kindergarten

*Ohio Academic Content Standards*
Kindergarten Physical Science
3. Describe and sort objects by one or more properties (e.g. size, color and shape).

List of Materials: Easter eggs, crayons, *Sorting* by Henry Pluckrose, Bags of Sponges

**Engage**
Teacher puts students into groups and students have to figure out why they were put there (e.g. color of shirt, all girls, and all sandals). Do this several times with different properties.

**Explore**
A sorting activity using crayons and Easter eggs of multiple colors and sizes. Start with the mixture and ask students something like “show me something about the objects” or another question without using the word “sort.” If some students are struggling, ask students who are on the right track to tell the class what they are doing. Then students should sort each of the groups by another characteristic. During this activity, students should be given the opportunity to describe their piles and why they chose them.

**Explain**
Ask the students to describe what they have been doing and facilitate a student created definition of this process. Ask the students if they know a word to describe what they have been doing. Once the students come up with the word “sorting,” or if not, you can tell them, read the book *Sorting* by Henry Pluckrose to students.

**Elaborate**
Teacher-facilitated discussion on examples (e.g. mail room, silverware drawer, desks) and non-examples (e.g. M&Ms, messy room, Jelly Beans) of sorting in everyday life. Can children think of places where sorting is used or places where sorting is not used?

**Evaluate**
Divide students into groups of no more than four. Give each group a bag of sponges and give them time to inspect the sponges. Then use the Rubric for Evaluation of Sorting to evaluate student performance and understanding.

**Sources:**

Name: ______________

**Rubric for Evaluation of Sorting**

<table>
<thead>
<tr>
<th></th>
<th>√+</th>
<th>√</th>
<th>√-</th>
<th>Notes</th>
</tr>
</thead>
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<tr>
<td>Cooperation in Group</td>
<td>Works well with others</td>
<td>Works well with others some of the time</td>
<td>Does not work well with others</td>
<td></td>
</tr>
<tr>
<td>Sorting Abilities</td>
<td>Finds more than one way to sort</td>
<td>Sorts into one distinct group</td>
<td>Items mixed up</td>
<td></td>
</tr>
<tr>
<td>Verbal Reasoning</td>
<td>Can describe multiple properties of items</td>
<td>Can describe one characteristic</td>
<td>Cannot articulate reasoning</td>
<td></td>
</tr>
</tbody>
</table>

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Appendix E

Informed Consent for K-2 Teachers
How does Children’s Literature Impact K-2 Teachers’ Views of Teaching Science through Inquiry?

Research Description:
This research project is constructed to gain a better understanding of the challenges faced by kindergarten through second grade teachers in teaching science. Throughout the spring and fall semesters of 2007, you will be asked to take part in several assessments, implement a 5E inquiry cycle into your classroom, and attend individual meetings in order to measure the outcomes of this project. You will be asked to answer questions from three surveys. The first is a demographic survey requiring 10 minutes of time. The Science Teaching Efficacy Beliefs Instrument, or STEBI, is an assessment of how a teacher views him/herself as a science educator, and you will be asked to take this three times over the course a year at no more than 30 minutes each. The Pedagogical Content Knowledge of Inquiry Science Teaching Assessment is an assessment of a teacher’s knowledge of teaching science through inquiry, and you will be asked to answer this twice over the course of a year requiring no more than 30 minutes each. You will be asked to implement one or two 5E inquiry cycles developed by the researchers, which include books chosen by the school teachers. The cycles can be carried out in one or several days depending on your desires. Two meetings, no longer than one hour, will be set up with you individually to discuss teaching science and the specific 5E cycle for your classroom. Finally, you will be asked to write one journal everyday during the 5E cycle and one journal after as a reflection, requiring about 30 minutes each.

Consent:
I understand that I am being asked to participate in a research study beginning in January 2007 and ending in December 2007. I understand I will be asked questions about myself and my teaching. These questions will be asked through the surveys, meetings, and journaling described above. If I wish, I may see copies of the surveys and journal prompts before I decide to participate. I understand the information gathered from me will be used as a part of a larger project attempting to understand the impact of children’s literature on K-2 teachers’ views of teaching science through inquiry.

I understand that all personally identifiable information will be kept strictly confidential and will not appear in any reports generated using the information gathered from the study. I understand that participation in this study is completely voluntary. I do not have to answer any questions I do not want to and can stop the process at any time and withdraw from the study. Withdrawing from the study will in no way affect my usage of funding provided through the Martha Holden Jennings Foundation. If I withdraw from the study, the information I have given up to the time of withdrawal will be retained for the study unless I request that it not be used.

Finally, I give my permission for the meetings to be tape recorded. I understand the purpose of recording is to assure that what I say is represented accurately in the research process. I have had the opportunity to ask any questions I might have and they have been answered to my satisfaction. By signing, I agree to participate in the research study.
If you have any further questions or concerns, please feel free to contact Kathryn Nafziger, Department of Chemistry and Biochemistry, 363 Hughes Hall, Miami University, Oxford, OH 45056 or email at nafzigkm@muohio.edu. You may also contact my research advisor, Dr. Stacey Lowery Bretz, at bretzsl@muohio.edu. If you have questions about your rights as a human subject contact the Office for the Advancement of Research and Scholarship (513-529-3734) or humansubjects@muohio.edu.

If you are willing to participate in this research project to better help elementary teachers in teaching science, please sign your name below.

____________________________________  ______________________
Research Participant                     Date

____________________________________  ______________________
Researcher                               Date

____________________________________  ______________________
Researcher                               Date
Appendix F

Interview Guide: First Meeting Questions for Teachers

1. What subject is your primary interest?

2. How comfortable are you with teaching the physical science content standards?

3. What are your views of the current science curriculum?

4. What do you enjoy about teaching science?

5. What do you dislike about teaching science?

6. What does the word inquiry mean to you with regards to teaching science? Does it have a positive or negative connotation to you?

7. Would you say you use inquiry in your classroom?

8. Describe one success you have experienced in teaching science.

9. Describe one difficulty you have experienced in teaching science.
Appendix G

Demographic Survey of Teachers

How does Children’s Literature Impact K-2 Teachers’ Views of Teaching Science through Inquiry?

1. Name: ________________________________

2. Email Address: __________________________

3. Telephone Number: ___________ School ___________ Home

4. Contact Preference: _____ Email _____ Home Phone _____ School Phone

5. Gender: _______ Male _______ Female

6. Date of Birth: ________________

7. What is your ethnicity?
   ___ African American/Black
   ___ American Indian/Alaska Native
   ___ Asian/Pacific Islander
   ___ Hispanic
   ___ White Caucasian
   ___ Other (please specify): ____________________________

8. Current Grade Teaching: ____________

9. Building:

10. Years Teaching Experience within School District: ____________________________

11. Total Years Teaching Experience: ___________________________________________

12. Have you taught anywhere outside School District? __________________________
    If yes, where and for how long? _____________________________________________
13. What is your highest degree attained? ____________________________________________

14. What universities/colleges did you attend? _______________________________________
   ____________________________________________
   ____________________________________________

15. What do you enjoy about teaching science? _________________________________________
   ____________________________________________
   ____________________________________________
   ____________________________________________

16. Please describe your experiences with teaching science through inquiry: ________________
   ____________________________________________
   ____________________________________________
   ____________________________________________
   ____________________________________________
Appendix H

Nature of Matter

1. How would you describe matter at the particle level? Explain your view of matter in terms of orientation and space between particles. (Feel free to draw pictures if that helps.)

2. A glass of cold milk sometimes forms a coat of water on the outside of the glass (Often referred to as 'sweat'). How does most of the water get there?

3. What is the mass of the solution when 1 pound of salt is dissolved in 20 pounds of water? (e.g. 19 lbs, greater than 20 lbs) Please include your reasoning for the answer you provide.

4. The circle on the left shows a magnified view of a very small portion of liquid water in a closed container.

![Diagram showing liquid water and evaporated water with labels and icons for water, oxygen, and hydrogen]

What would the magnified view show after the water evaporates?

![Circle showing a magnified view of evaporated water]

Please give an explanation for your drawing.


5. When a liquid is heated to a gas, does A or B better describe the particles of the gas? Please explain why your answer is best.


### Science Teaching Efficacy Beliefs Instrument

*For In-Service Teachers*

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

- **SA =** Strongly Agree
- **A =** Agree
- **UN =** Uncertain
- **D =** Disagree
- **SD =** Strongly Disagree

<table>
<thead>
<tr>
<th>Statement</th>
<th>SA</th>
<th>A</th>
<th>UN</th>
<th>D</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. When a student does better than usual in science, it is often because the teacher exerted a little extra effort.</td>
<td>SA</td>
<td>A</td>
<td>UN</td>
<td>D</td>
<td>SD</td>
</tr>
<tr>
<td>2. I am continually finding better ways to teach science.</td>
<td>SA</td>
<td>A</td>
<td>UN</td>
<td>D</td>
<td>SD</td>
</tr>
<tr>
<td>3. Even when I try very hard, I don't teach science as well as I do most subjects.</td>
<td>SA</td>
<td>A</td>
<td>UN</td>
<td>D</td>
<td>SD</td>
</tr>
<tr>
<td>4. When the science grades of students improve, it is most often due to their teacher having found a more effective teaching approach.</td>
<td>SA</td>
<td>A</td>
<td>UN</td>
<td>D</td>
<td>SD</td>
</tr>
<tr>
<td>5. I know the steps necessary to teach science concepts effectively.</td>
<td>SA</td>
<td>A</td>
<td>UN</td>
<td>D</td>
<td>SD</td>
</tr>
<tr>
<td>6. I am not very effective in monitoring science experiments.</td>
<td>SA</td>
<td>A</td>
<td>UN</td>
<td>D</td>
<td>SD</td>
</tr>
<tr>
<td>7. If students are underachieving in science, it is most likely due to ineffective science teaching.</td>
<td>SA</td>
<td>A</td>
<td>UN</td>
<td>D</td>
<td>SD</td>
</tr>
<tr>
<td>8. I generally teach science ineffectively.</td>
<td>SA</td>
<td>A</td>
<td>UN</td>
<td>D</td>
<td>SD</td>
</tr>
<tr>
<td>9. The inadequacy of a student's science background can be overcome by good teaching.</td>
<td>SA</td>
<td>A</td>
<td>UN</td>
<td>D</td>
<td>SD</td>
</tr>
<tr>
<td>10. The low science achievement of some students cannot generally be blamed on their teachers.</td>
<td>SA</td>
<td>A</td>
<td>UN</td>
<td>D</td>
<td>SD</td>
</tr>
<tr>
<td>11. When a low achieving child progresses in science, it is usually due to extra attention given by the teacher.</td>
<td>SA</td>
<td>A</td>
<td>UN</td>
<td>D</td>
<td>SD</td>
</tr>
</tbody>
</table>
12. I understand science concepts well enough to be effective in teaching elementary science.

13. Increased effort in science teaching produces little change in some students' science achievement.

14. The teacher is generally responsible for the achievement of students in science.

15. Students' achievement in science is directly related to their teacher's effectiveness in science teaching.

16. If parents comment that their child is showing more interest in science at school it is probably due to the performance of the child's teacher.

17. I find it difficult to explain to students why science experiments work.

18. I am typically able to answer students' science questions.

19. I wonder if I have the necessary skills to teach science.

20. Effectiveness in science teaching has little influence on the achievement of students with low motivation.

21. Given a choice, I would not invite the principal to evaluate my science teaching.

22. When a student has difficulty understanding a science concept, I am usually at a loss as to how to help the student understand it better.

23. When teaching science I usually welcome student questions.

24. I don't know what to do to turn students on to science.

25. Even teachers with good science teaching abilities cannot help some kids learn science.

Appendix J

Pedagogy of Science Inquiry Teaching Test (POSITT)*

Directions:

The National Science Education Standards recommend inquiry approaches to science teaching, as well as the promotion of higher order reasoning skills in learners.

Each item begins with a classroom teaching vignette, followed by a question about the pedagogy in this vignette with regard to inquiry and higher-order thinking skills.

Please select the best response for each item and then write a few sentences about why you chose that response over the other possible responses.
Vignette #1

Mr. Lowe is a 3rd grade teacher. Two of his *eventual* objectives are for students to learn at a *simple* level about the relationship between form and function.

He begins a specific lesson on fish by showing an overhead transparency of a fish, and then labeling several parts of the fish as shown.

**Which of the following is the best evaluation of the lesson so far? (Please circle your response.)**

A. This is a good lesson so far, because the teacher is clearly and systematically introducing the vocabulary that the children will need for further studies of fish.

B. This is a good lesson so far, because by learning the names of the fish parts, the students are more engaged and will ask appropriate questions about their function.

C. This lesson is not off to a good start, because it begins with the teacher giving the children information about fish, before any attempt to develop a sense of questioning or investigation on the part of the students.

D. The lesson is not off to a good start, simply because it begins with the teacher doing the talking, which is never a good idea.

E. This lesson is not off to a good start, because the students are not doing anything "hands-on." There should always be real fish for students to observe, so they would connect the lesson to the real world.

**Why did you choose this response over the other possible responses?**

*Schuster, D.; Cobern, W.; Schwartz, R.; Applegate, B.; Vellom, P. *Pedagogy of Science Inquiry Teaching (POSIT)*. Western Michigan University. 2006. (used with permission)
Vignette #2

Five teachers have different ways of introducing elementary students to the relationship between force and motion. Each of them plans to use a lesson activity involving a trolley with little friction; one student can sit in the trolley while another can pull it along by exerting force on the handle.

The goal is that students should gain a conceptual understanding of the scientific relationship between motion and force, viz. that an applied force will cause an object to change its motion, i.e. speed up or slow down. (Newton’s second law).

The five teachers devise different lesson plans. To achieve recommended science learning goals, which of the following approaches is best? (Please circle your response.)

- **Teacher Arthur:** Starts by writing a main heading on the board: ‘Newton’s second law of motion’, then dictates the law (in conceptual terms) for students to write down. He then explains the law carefully, and illustrates it with a sketch of a trolley being pulled. Along the way he gives students the opportunity to ask questions. Finally he has students confirm the law experimentally, by checking what happens to a trolley when a person pulls it with a constant force.

- **Teacher Betty:** First has students explore and observe what happens to the trolley when a steady force is applied to it. Then asks them to describe the kind of motion that occurs. She elicits possible questions of interest about forces and motions, and then asks for suggestions for a possible ‘law’ that would describe their observations. Having put forward a law or laws from discussion, students then test it by making predictions in various situations and trying it out. They finally write their own statements of the law they have generated.

- **Teacher Carl:** Gives students freedom to try out anything they wish with the trolleys, intending that they should enjoy the hands-on activity and eventually discover on their own the relation between force and motion. He does not impose structure on the activity, nor tell students what to do, but is available for discussion. He does not give the ‘correct answers’ to their questions, but instead asks questions in return. He does not give students the ‘correct’ law at the end of the lesson, since this is not the only point of the lesson.

- **Teacher Donna:** As a prelude to Newton’s second law of motion, Donna introduces the term ‘acceleration’, defines it, and has students write it down. She then discusses the concept carefully, since students often have difficulty with it. Thereafter she states Newton’s second law of motion, in the form ‘acceleration is proportional to net force’ and explains it. Students then confirm, by pulling the trolley, that a force produces acceleration, and that acceleration increases with the force.

- **Teacher Eric:** He has several students in succession read paragraphs aloud from the textbook, since the text treats the topic very clearly and correctly. He calls on students to restate the law, and encourages them to ask questions. He then demonstrates the law using the example of the pulled trolley, having students perform the activity in front of the class, to confirm that the results agree with the textbook statement.

**Why did you choose this response over the other possible responses?**

Vignette #3

Ms Lefevre’s third grade class has been doing a long investigation activity with earthworms. In addition to teaching her students about the basic needs of earthworms, Ms Lefevre also wants to develop their skills of observing, investigating, recording and seeking patterns. Several groups had been making observations and taking data over some time, and she next brought the class together around the data chart, so that they could all look for patterns in their observational data. She wanted her students to rely on evidence to develop their knowledge. During this analysis, a student pointed out that data collected by one group seemed to contradict data collected by another group.

What should Ms. Lefevre do in this situation? (Please circle your response.)

A. Tell the students which of the two sets of data was correct and cross out the other data, so that none of the students would get the wrong ideas about earthworms.

B. Ask the students to suggest ways to resolve the issue, valuing any response that relied on evidence, e.g. re-examining recorded data or comparing procedures, repeating or taking more observations.

C. Ask everyone to look at the two data sets and to pick the one they thought was right. Then, have a show-of-hands vote to see which one should stay and which should be crossed off. This would ensure that the data that remained reflected the majority view.

D. Tell the students, “Since the data conflicts and we don’t know the answer, I will look this up and get back to you tomorrow.” Then, move on to look at the rest of the data with the class.

E. Ask the students to read through the topic resources again to see if they can find information that will resolve the dispute.

Why did you choose this response over the other possible responses?

Vignette #4

Ms Jansen starts to teach the phases of the moon. Her aim is that students come to understand that the different appearances of the moon are due to its round shape being lit by the sun at different angles during the month.

She begins by taking the class outside when the sun is low and the moon is about ‘half’. She draws students’ attention to the positions of moon and sun, gestures to indicate how the sun is lighting the moon from the side, and explains that they are seeing only the lit half.

What is the best comment on Ms Jansen's approach so far?

A. This is a good inquiry start because the students actually observe the real thing for themselves, rather than a book diagram, as a basis for understanding Ms Jansen's explanation, which she relates directly to what they are seeing.

B. This is not a good inquiry start, because although the students observe the real thing, Ms Jansen presents them with the explanation without first having them wonder about it and discuss possible ideas.

Why did you choose this response over the other possible response?

Vignette #5

Ms Chavez starts to teach the phases of the moon. Her aim is that students come to understand that the different appearances of the moon are due to its round shape being lit by the sun at different angles during the month.

She starts in a darkened classroom, by having one student hold a large white ball overhead, while another shines a flashlight at it from one side. Several students describe what they see, which turns out to be different from different places in the room, around the ball. Ms Chavez promotes discussion of why this might be, allowing students to move around or move the flashlight around to test their ideas. She will next take them out to observe the sky.

What is the best comment on this approach?

A. This is not a good start. Although this is participatory, students should always see the actual real phenomenon (the moon) for themselves from the beginning, rather than a prepared model.

B. This is a good start, because students have a relevant experience, and make sense of their observations, as a basis for understanding illumination, so they would be well prepared to tackle actual sky observations for themselves next.

Why did you choose this response over the other possible response?

Vignette #6

Mr Yang takes his students outside to observe a crescent moon, with the sun low in the sky, and asks students about their ideas about why the moon looks like that. One student Kim states that it is caused by the shadow of the earth on the moon.

What should Mr Yang do?

A. He should correct this misconception immediately, by stating that this is not the case; it is important to do this in case a wrong idea becomes entrenched for the class.

B. He should ask Kim and the class to consider this idea and discuss whether or not it can be supported by the evidence, by looking at the relative positions of the sun, moon and earth.

Why did you choose this response over the other possible response?

Appendix K

Journal Prompts for First 5E Learning Cycle

Journals during 5E Cycle Implementation

• Please describe your experiences implementing this 5E Cycle into your classroom.
• What were your goals for today?
• What did you do/say?
• What did your students do/say?

Journal after 5E Cycle Implementation

• What are the strengths of the 5E model for your students?
• What are the challenges of the 5E model for your students?
• Which part(s) of the 5E cycle were the most successful?
• Which part(s) of the 5E cycle were the most successful?
• What could be done differently to help your students learn more?
• How has this experience change your perceptions of teaching science?
• Comment on the use of children’s literature to teach science.
Appendix L

Journal Prompts for Second 5E Learning Cycle

Journal during 5E Cycle Implementation

• Please describe your experiences implementing this 5E Cycle into your classroom.
• What did you do/say?
• What did your students do/say?

Journal after 5E Cycle Implementation

• What did you think about the 5E model as a structure for inquiry?
• Did you think about the science concepts at a deeper level during the 5E?
• Did the activity deepen your understanding of the science content? Explain.
• Did the activity leave you with any questions about the science concept? If yes, what were they?
• What could be done differently to help your students learn more?
• How has this experience changed your perception of teaching science (like or dislike)?
• Comment on the use of children’s literature to teach science.
Appendix M

Second Interview Guide: Questions of Teachers

1. Tell me about your experience teaching science in the past year.
   a. 5Es
   b. Particularly good experience
   c. A time when you were frustrated

2. How has your confidence in teaching science changed in the past year?
   a. What has caused this change?

3. What does the word inquiry mean to you with regards to teaching science? Does it have a positive or negative connotation to you? [Show the teacher their prior response]

4. How do you think your overall knowledge of inquiry has changed in the past year?
   a. What has caused this change?
   b. Which of the following best describes your understanding of inquiry?
      A. I don’t know it.
      B. I know it but can’t put it into practice.
      C. I know it and can put it into practice well.
   c. Explain.

5. How knowledgeable do you consider yourself about the science standards?
   a. What standards do you find difficult to teach?
   b. How does this difficulty impact your teaching?

6. What are your goals in the future for teaching science?
   a. Do you plan to use the 5Es?
   b. Would you consider making your own?
Appendix N

Chemical Concept Inventory53 Questions adapted in PNM Interview

Question 2 of PNM Interview:

3. A glass of cold milk sometimes forms a coat of water on the outside of the glass (Often referred to as 'sweat'). How does most of the water get there?
   a. Water evaporates from the milk and condenses on the outside of the glass.
   b. The glass acts like a semi-permeable membrane and allows the water to pass, but not the milk.
   c. Water vapor condenses from the air.
   d. The coldness causes oxygen and hydrogen from the air combine on the glass forming water.

Question 3 of the PNM Interview:

4. What is the mass of the solution when 1 pound of salt is dissolved in 20 pounds of water?
   a. 19 Pounds.
   b. 20 Pounds.
   c. Between 20 and 21 pounds.
   d. 21 pounds.
   e. More than 21 pounds.
Question 4 of the PNM Interview:

6. The circle on the left shows a magnified view of a very small portion of liquid water in a closed container.

![Key diagram]

Liquid Water

Evaporated Water

What would the magnified view show after the water evaporates?

(a)  
(b)  
(c)  
(d)  
(e)
Appendix O

Science Teaching Efficacy Beliefs Instrument (STEBI) Scoring

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### Appendix P

Pedagogy of Science Inquiry Teaching Test (POSITT) Scoring

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