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TEACHERS' SCIENTIFIC KNOWLEDGE, TEACHING PRACTICE, AND STUDENTS' LEARNING ACTIVITIES: CASES OF THREE ELEMENTARY CLASSROOM TEACHERS

By

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ABSTRACT

TEACHERS' SCIENTIFIC KNOWLEDGE, TEACHING PRACTICE, AND STUDENTS' LEARNING ACTIVITIES: CASES OF THREE ELEMENTARY CLASSROOM TEACHERS

By

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The purposes of this dissertation study are to better understand what specific types of scientific knowledge and practice three elementary teachers exhibit, and to examine how they use their scientific knowledge in their classroom teaching practice to provide students' opportunities to learn science when teaching condensation in the context of a unit on the water cycle. By comparing and contrasting three cases of elementary classroom teaching, this study discusses what kinds of scientific knowledge and practice are fundamental for teaching elementary science for scientific understanding.

The data include structured interviews (content, pre- and post- observation, and stimulated recall), videotaped classroom observations, and collections of teachers' and students' written artifacts. Data were collected prior to, during, and after the three teachers taught condensation to fifth grade students. The data were analyzed in three contexts: interviews, teaching practices, and students' classroom activities. This made it possible to clarify which characteristics of teacher's scientific knowledge influenced which aspects of their teaching practice.

Data analysis shows that teachers' scientific knowledge were closely associated with their teaching practice and students' classroom activities. Two characteristics of the teachers' scientific reasoning emerged as especially important. The first concerned how teachers connected observations of condensation with patterns in those observations (e.g.,

condensation occurs when warm moist air cools) and with explanations for those patterns (e.g., condensation is water vapor that changes to liquid water). Two teachers were careful to connect observations with patterns in their own thinking and in their classroom teaching. One of those teachers also connected the observations and patterns to scientific explanations. In contrast, the third teacher focused on listing scientific terms with little elaboration with specific observations and patterns.

The second important characteristic of teachers' scientific reasoning concerned their views of science. One teacher enacted a largely inductive, empirical view, helping her students to observe examples of condensation, to find patterns in their observations, and to label the patterns as condensation. The second teacher engaged the students in a detailed series of experiments and data-based arguments designed to demonstrate that the liquid water in condensation was originally water vapor in the air. The third teacher focused on teaching students facts and vocabulary from authoritative sources, including their textbook and dictionaries.

This study discusses what it means to have a deep understanding of fundamental science for elementary teachers. Making connections among observations, patterns, and explanations is important for students to understand the scientific world. Scientific practices, inquiry and application, play an important role to help teachers and students connect observations, patterns, and explanations. The implications to elementary science teacher education are discussed, considering how we can prepare elementary teachers to use scientific knowledge in their teaching practice.

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In looking back at my dissertation study, many memories from the past several years struck me. In the summer of 2000, I arrived at Michigan State University to study science teacher education. Around that time, it did not seem to me that it could be feasible to expect to ever get my dissertation in my hands, due to at least several difficulties I had to face: language, culture, my own naïve ideas and ability about the field I had chosen, etc. Nevertheless, I finally arrived here after getting through all of the hardships I was willing to bear. Thinking back on my time in graduate school at Michigan State, the biggest thing left in my mind is the surprising fact that I actually experienced much joy, happiness, and excitement at having this unique chance to seriously study about education.

I have always realized that I am very lucky not only to have this great opportunity, but also to get enormous support and warm friendship from others. I would like to specially thank them all. My advisor, Charles (Andy) Anderson, is my wonderful teacher, mentor, and professor, who guided me to the current place. His teaching, warm encouragement, and patience with me were a huge part of the cognitive apprenticeship I engaged in through my graduate school life. Ed Smith, Tom Bird, and Ralph Putnam have read the manuscript of my dissertation chapters and given me comments and feedback. I especially thank Ed for his warm and consistent support and encouragement to continue my studies.

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Chapter One

Situating the Study

For decades, there has been a common agreement that teachers need scientific knowledge for good science teaching (Carlsen, 1991; Hashweh, 1987; Schwab, 1978; Putnam & Borko, 2000; Wilson & Berne, 1999). The underlying belief is that with better scientific knowledge, science teachers engage in effective teaching performance to make good curricular and instructional decisions to help elementary students learn science better.

People I have worked with in elementary science education often stressed how important it is for teachers to have "good" or "fundamental" scientific knowledge for teaching young students. They often say that knowing a certain range of scientific concepts in a variety of subjects, covering biology, geology, physics, and chemistry, would help them teach science better. Given the reality that many elementary teachers often do not have sound science content background, the teachers' and teacher educators' perception that we need more scientific knowledge and concepts for better science teaching seems understandable.

The situation I faced with elementary school teachers and educators is not different from that depicted in science education reform documents, which include a plethora of science content standards. For instance, national and state science education standards provide lists of a variety of scientific propositions and concepts that science teachers are expected to know (e.g., see American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 1996, 2000). The suggested scientific concepts and propositions around various science subjects represent the reform documents' perspectives about what science teachers and teacher educators are supposed to cover and address in science teaching, listing a variety of scientific topics.

Despite the belief that gaining an array of scientific knowledge is essential, however, my conversations with the elementary folks have given me an impression that we have not considered much about what we mean by "good" scientific knowledge for the "good" teaching practice we need. Further, the science education reform documents list a variety of scientific knowledge, which mostly focus on listing the scientific propositions around various science topics, without helping teachers understand what kinds and aspects of scientific knowledge we need to look for and develop in elementary science teaching.

Given the emphases of teachers' gaining more scientific propositions in elementary science education, there have been concerns about teachers' gaining mastery of a list of the scientific knowledge and propositions (Barba, 1998). Scientific concepts are so complex and abstract that science teachers find enormous difficulty attaining scientific understanding for all of the various science topics (Brockmeier & Harre, 1997; Collins & Ferguson, 1993). Further, teachers' acquisition of the listed scientific knowledge or array of various scientific concepts does not necessarily guarantee their effective teaching practice that accompanies students' scientific sense making (Van Driel & Verloop, 2002; Wiske, 1998).

Therefore, in my dissertation study, I seek to understand what kinds of scientific knowledge would be crucial and fundamental for teaching elementary science, addressing a question: What does it mean for science teachers to have a profound understanding of fundamental science? In math education, Liping Ma (1999) has studied what she describes as "profound understanding of fundamental mathematics." Ma suggests fundamental ways in which teachers teach mathematics for understanding. In this study, I also address a substantial question about science teachers' scientific knowledge and practice, discussing what it means for elementary teachers to have a profound understanding of science.

To answer the question, I examine three cases of elementary teachers to understand their scientific knowledge and practice in interviews and classroom teaching practices, and I also investigate how their knowledge and teaching practice are related to their students' opportunities to learn science in classroom activities.

Research Questions

The purposes of this dissertation study are to better understand what types of scientific knowledge and practice three elementary teachers employ, to examine how they use their scientific knowledge in their classroom teaching practice to provide students' opportunities to learn science when teaching condensation in the context of a unit on the water cycle and to study which aspects of teachers' scientific knowledge affect which characteristics of teaching practice and students' learning activities. By comparing and contrasting three cases of elementary classroom teaching, I ultimately discuss what kinds of scientific knowledge and practice are fundamental for teaching elementary science for scientific understanding. The detailed research questions are as follows:

1. What specific types of scientific knowledge and practice about condensation do three elementary teachers exhibit in interviews?
2. How are teachers' scientific knowledge and practice related to their classroom teaching practices and their students' learning activities?

Previous Research

Research on teachers' scientific knowledge and practice goes back for decades (Borko & Putnam, 1996; Putnam & Borko, 2000). Despite few studies focusing on science teachers' scientific knowledge, several key studies have contributed to our understanding of teacher knowledge and teaching practice. Most of the previous studies have provided us with extensive categories of teacher knowledge, but they do not help us see what specific types of scientific knowledge are fundamental for science teachers to need to look for, and how those knowledge claims are related. Bearing in mind these limitations, I review the types of teachers' scientific knowledge and practice identified by these previous studies and the relationships between the knowledge and their teaching practice, and then I also point out the problems and limitations in the current research literature in order to flesh out the necessity of this study.

The types of teacher's scientific knowledge and practice

Schwab's (1978) framework has contributed to the development of science teacher's scientific knowledge as a key piece of work on other general teacher education literatures. Schwab (1978) emphasized that teachers' subject matter knowledge consists of the substantive and syntactical structures of a discipline. Substantive structures are the ways in which the ideas, concepts, and facts of a discipline are organized. They refer to knowledge of the global structures or principles of conceptual organization of a discipline. They include the key principles, theories, and explanatory frameworks of the discipline. Syntactical structures, on the other hand, are rules of evidence and proof that guide inquiry in a discipline – the ways of establishing new knowledge and determining the validity of claims. According to Schwab, they include knowledge of the "historical and philosophical scholarship on the nature of knowledge" in a discipline (Shulman, 1987). Schwab argues that teachers need to have a deeper understanding of this distinctive feature of subject matter knowledge for their effective teaching for understanding in each discipline.

Grossman (1990) extended Schwab's framework by expanding the category of subject matter knowledge to include both the knowledge of major facts and concepts within a field and the relationship among them. Grossman argued that subject matter knowledge includes knowledge of the content as well as knowledge of the substantive and syntactic structure of the discipline. She made an explicit distinction between content knowledge itself and the structures of a discipline – substantive and syntactic. Grossman also elaborated further about the structures in subject matter. She specified the substantive structure as the various paradigms within a field that affect both how the field is organized and the questions that guide further inquiry. The syntactic structure includes an understanding of the canons of evidence and proof within the discipline, or ways in which the knowledge claims are evaluated by members of the discipline.

Kennedy (1990) distinguished Schwab's syntactical structure of the discipline from the methods of inquiry. She explicated the knowledge of the methods of inquiry, which includes a set of assumptions, rules of evidence, or forms of argument that are or can be employed by those who contribute to the development of discipline. Kennedy argued that the methods of inquiry provide practitioners in the field with a way to evaluate new ideas and to challenge or defend them, to interact with one another and with the content, and to function within their field. Especially she emphasized that it is important for teachers to have thorough reflective ability to evaluate and critique the existing body of knowledge claims through the process of justifying and verifying the knowledge constructed.

As noted earlier, scientific inquiry is regarded as an essential scientific practice. In science education, the notion of syntactical structure has been especially widely discussed. As Schwab (1978) suggested, the teaching of scientific inquiry is a priority in science education, and teachers teach students both to conduct investigations in inquiry and to view science itself as a process of inquiry. He stressed syntactical structure as important teacher scientific knowledge in science teaching. According to him, as an essential scientific knowledge, science teachers need to build the knowledge of rules of evidence and argument that guide inquiry in the discipline – the ways of establishing new knowledge and determining the validity of claims (Schwab, 1978; Shulman, 1986).

Shulman (1986) developed a conceptualization of the diverse knowledge domains, such as subject matter knowledge (both substantive and syntactical), pedagogical content knowledge (PCK), and pedagogical knowledge, needed for teaching. Shulman introduced the concept of PCK that refers to teacher's amalgamation of content and pedagogy into an understanding of how particular topics, problems, or issues are organized and represented to the students. Shulman's idea of PCK is especially helpful for us to understand how scientific disciplinary knowledge can be effectively taught to students. It implies that successful science teaching practice can be achieved not only by deep subject matter knowledge, but also by its extensive combination with pedagogical strategy, assessment of students, and using professional resources. Shulman stressed that the development of PCK for effective science teaching can be made through the combination of the various problems of practice.

Hashweh (1987) particularly specified science teacher knowledge, independent from Schwab's framework. He identified four relatively independent dimensions of subject matter knowledge related to specific science topics (e.g. simple machines and photosynthesis). They included knowledge of topic, knowledge of other discipline concepts, knowledge of discipline higher-order principles or conceptual schemes, and knowledge of instructional approaches or of different ways of relating the topic to other discipline "entities" such as other topics, concepts, principles, or conceptual schemes. However, despite his categorization of science teacher knowledge, his focuses were more on the various science topics or concepts instead of the types of scientific knowledge and practice.

Relationships between teachers' scientific knowledge and teaching practice

Studies have documented the general conclusion that subject matter knowledge affects teaching practice. Ferguson and Womack (1993) studied whether or not teacher content knowledge makes a positive difference in teaching performance and found that education coursework is a more powerful predictor of teaching effectiveness than measures of content expertise. Based on their statistical findings, they argued that it would be counterproductive to increase content course exposure at the expense of coursework in pedagogy. They argued that content knowledge has a more modest impact on teacher practice than pedagogical skills, leading to the question of how much teacher content knowledge can affect effective teaching practice.

However, in math education, Ball (1988) found that subject matter preparation affects preservice teachers' teaching performance for helping students understand the essential mathematics concepts. The study reported that with sound subject matter knowledge, the teachers were able to tell the right story and correct students' misconceptions and misunderstanding. Ball seems to emphasize the importance of mathematical knowledge for teaching, not just mathematical knowledge itself.

Mullens, Murnane, and Willett (1996) found that students' mathematics achievement was related to their teacher's strong command of the subject. They argued that teacher preservice education that prepares teachers for increasing content knowledge has positive effects on student achievement.

However, Ball (1988) argues that what is needed is not strong command of the subject, but strong command of subject in teaching practice. Ball's argument provides us a chance to differentiate teacher's subject matter knowledge for teaching from their disciplinary knowledge.

These findings, which did not clearly differentiate the Ball's distinctions, are in agreement with some of the empirical studies in science education. For instance, Supovitz and Turner (2000) asserted that teachers' content preparation has a powerful influence on teaching practice and classroom culture. This empirical study employed hierarchical linear modeling to examine the relationship between professional development focusing on enhancing teacher's subject matter knowledge and teachers' teaching practice. Monk (1994) found that there are positive relationships between teachers' subject matter preparation and teaching practice that ultimately lead to improvement in students' performance. Van Driel, Beijaard, & Verloop (2001) suggested that science teachers' practical knowledge and content knowledge contribute to the improvement of their teaching practice. Individual teacher's efforts to improve their science knowledge make a significant difference in ensuring the quality teaching practice. The authors argue that systemic support is necessary in enhancing teacher science knowledge in addition to the individual teachers' efforts.

The general findings of teachers' scientific knowledge preparation showed that science content knowledge preparation was a promising factor to explaining teacher's performance in spite of uneven evidence supporting the positive influence of teacher knowledge.

To link teacher's scientific knowledge to the particular teaching practice, I review which parts of teaching practice are influenced by teachers' scientific knowledge. In this review, I include three parts of teaching practice: planning, teaching, and assessing.

In planning science lessons, when a science teacher lacked subject matter knowledge and deep understanding of the science activities, the teacher showed difficulties in effectively implementing a reform curriculum and making a reasonable plan (Hashweh, 1987). Smith and Sendelbach (1982) found that because of the lack of content knowledge, a teacher's instruction was led by ineffective arbitrary decisions and the limited use of reform teaching materials. The teacher repeated the common routines of typical, often ineffective, activity based on her persistence in traditional ways of teaching science.

Carlsen (1991) found that with deep subject matter knowledge, four biology teachers were highly likely to create an instructional context rich in the substance and syntax of science curriculum. With weak subject matter knowledge, however, the teachers frequently planned to cover less substantive materials, spent more time talking about things unrelated to the topic of the lesson, followed the prepositional structure of the textbook, and presented facts as discrete, unrelated propositions.

In teaching science content, science teachers with limited science knowledge such as facts, definitions and simple formulas tended to closely follow the textbook information either to reduce science only to a body of known facts or to persist the performance for grade exchange (Anderson & Smith, 1987; Carlsen, 1991, 1993; Smith, 1990).

van Driel, Verloop, and de Vos (1998) pointed out that when chemistry teachers' transformed subject matter knowledge particularly in chemical equilibrium to pedagogical content knowledge, they were successfully working in promoting students' conceptual change by effectively discussing anomalous results of certain experiments with students. For facilitating student understanding, the authors emphasized that it is important to effectively transform teacher's subject matter knowledge to student learning and flexibly relate the transformations to student conceptual understanding.

Carlsen (1988, 1991, 1993) also found that science teachers' subject matter knowledge affects classroom discourse in biology teachers' classrooms. Using statistics on individual teacher and student utterances, Carlsen reported that when teachers understood the topics they were teaching well, they encouraged student questions and other students' participation in discourse. Without good content knowledge, the teachers tended to dominate students' conversations and continue delivering the factual information to students.

In assessing students' learning, given their limited subject matter knowledge, Kennedy (1990) and Jang, Richmond, and Anderson (2003) found that teachers often simply wanted to assess if students acquired certain facts such as textbook lists and correct definitions that their lesson objectives specified. Hashweh (1987) suggested that without understanding of knowledge and practice of scientific inquiry, science teachers often emphasize the test questions requiring direct lower level of recalling factual information contained in the textbook, spend the time on simple manipulation of the tools, frequently tend to teach the concepts superficially, and also orient their science time to the basic skills and factual memorization rather than towards higher order thinking and conceptual understanding.

In summary, the general conclusion from the previous research was that teacher's sound scientific knowledge affects teaching practice about lesson planning, content teaching, and students' assessment. However, these findings did not inform us of what particular types of scientific knowledge and practice are useful for teaching practice.

Problems of the current research literature on teacher's scientific knowledge

Given the review of the prior studies, I argue that there are problems and limitations of the research on teacher's scientific knowledge and practice.

First, I argue that the discussions of teachers' scientific knowledge tend to be too broad and general. The general categorization of teacher knowledge does not lead us to better understand what aspects and components of teacher knowledge and teaching practice are important. For instance, Schwab (1978) emphasized scientific inquiry as based on the syntactical structure of scientific knowledge. Kennedy (1990) also emphasized the methods of inquiry and discussed the skills related to them. However, their notions of inquiry tended to be not obvious. Although he stressed the importance of scientific inquiry as essential teacher knowledge, Schwab neither made clear what that means, nor specified what particular types of knowledge are necessary for good teaching practice for enacting the inquiry. In her emphasis on inquiry as important teacher knowledge, Kennedy did not address what aspects of science knowledge and practice are necessary for successfully enacting the methods of inquiry either.

Second, I also argue that the existing literatures support the general conclusion that more scientific knowledge is associated with better teaching practice, but it does not generally help us understand the mechanisms – "*How*" does this happen? Despite the general consensus that teachers' scientific knowledge affects teaching practice, it does not clearly explicate "*how*" the knowledge actually affects teaching performance. Most current literatures loosely discuss this issue.

For instance, existing studies on teacher knowledge do not pay close attention to the relationship between scientific knowledge and practice. For example, Schwab (1978) argued the importance of substantive and syntactical structure of knowledge. His notion of knowledge articulates the dichotomous aspects of knowledge that entail ways and skills of knowing such as procedural knowledge, as well as the conceptual aspects of knowledge such as science concepts. But he did not relate the types of knowledge to scientific practice or pedagogical practice in the classroom and rarely discussed how the knowledge segments could affect practice.

Carlsen (1991, 1993) discussed that knowledgeable teachers are better at organizing and teaching their science lessons in a way that students can actively engage in classroom discussions and discourse to help themselves develop scientific understanding. He compared knowledgeable teachers with less knowledgeable counterparts. However, he did not consider what kinds of differences in the teachers' scientific knowledge led the differences in teaching practice in planning and teaching of science topics.

Moreover, there were few studies looking at how teachers' scientific knowledge and teaching practice influence students' classroom performance. I argue that to discuss whether teachers' knowledge or practice are effective or not, it is also critical for us to consider whether the knowledge and teaching practice help the students learn science better, by looking at how students interact with and react to teachers' teaching practice and demonstrate their learning in the classroom.

In summary, few of the existing studies help us understand which aspects of scientific knowledge actually influence which characteristics of teaching practice. Thus we are less informed of what kinds of scientific knowledge and practice we need to develop for helping students make sense of the scientific world in classroom teaching and learning.

As stated earlier in my research questions, I am interested in looking at how elementary teachers' scientific knowledge and practice are related to their teaching practice and students' classroom activities?. But, the limitations in the current research literatures prevent my study from providing satisfactory answers to my research questions. For instance, making too general a categorization of teacher knowledge would not help me explicate how the particular features of scientific knowledge could be related to the particular characteristics of teaching practice.

Therefore, to track down the mechanism of the interplays among teachers' scientific knowledge, teaching practice, and students' classroom performance, considering the limitations of the current literature, I now propose an alternative analytical and theoretical framework that addresses the types of scientific knowledge and the relationship between the knowledge and practice.

The Analytical Framework

I propose an analytical framework to examine elementary teachers' scientific knowledge and practice. The framework explicates the nature of scientific knowledge and practice. It provides a description of scientific practice, inquiry and application, which is comprised of three types of scientific knowledge: experiences, patterns, and explanations (Anderson, 2003).

There are several reasons that I employ this framework for this study. First, the framework explicates what types of scientific knowledge and practice are involved in understanding science. So it helps me examine teachers' different types of scientific knowledge and practice. Second, this framework particularly helps me look at teachers' various ways or strategies, which I call sense-making strategies, to develop the types of scientific knowledge and practice (e.g. Anderson, 2003). It shows what different approaches teachers choose to engage in making sense of science and helping students understand science, while developing the particular types of scientific knowledge and practice. Finally, I find this framework useful to define what it means to understand science. The meaning of scientific understanding has been often viewed as very complicated and abstract (Gallagher, 2000; Wiske, 1998). The framework conveys the fundamental meaning of what scientific understanding we need to know.

Thus, I propose that the framework of scientific knowledge and practice play a role as useful tool for me to examine elementary teachers' scientific understanding and various ways or approaches to make sense of science. Next I will explain the framework in more detail.

Scientific knowledge and practice

To discuss what constitutes important scientific knowledge and practice, I think that it is important to first understand the nature of scientists' practice. Whereas school science focuses frequently on book knowledge as the separated facts, definitions, diagrams and sequences of events, and problem-solving skills, scientists' science involves a different quality and feature of knowledge and practice while they work on making sense of the material world (Anderson, 2003). Paying attention to the features of scientists' science is valuable and important to school science because it helps us understand how scientific knowledge and practice are actually constructed and developed.

Scientific Knowledge. In elucidating scientists' science, Anderson (2003) lays out the fundamental nature of scientific knowledge and practice (Figure 1). As shown in Figure 1, there are three types of scientific knowledge: experiences, patterns, and explanations.

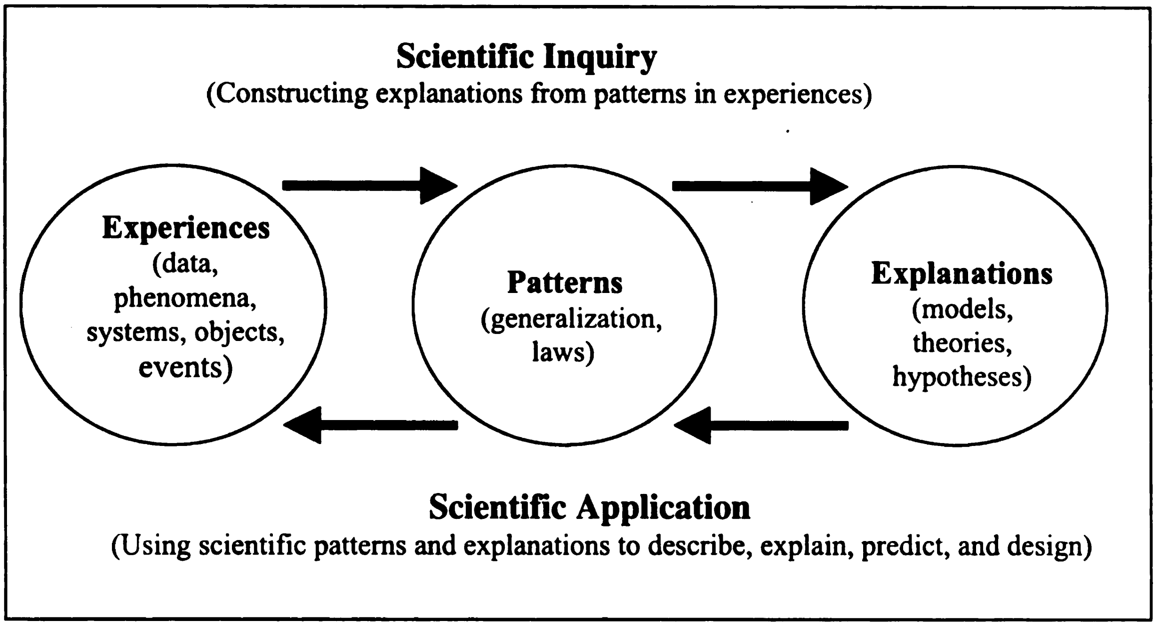

Figure 1. Analytical framework for scientific knowledge and practice

A. Experiences in the scientific world. All science investigation and enterprises include building experience through the collection of data and observations. Scientific knowledge is established by a concrete connection with the natural and material world. Scientists work intensely on the vast numbers of data containing measurements, descriptions, reports, findings, drawings, photographs, and observations of the physical and biological world comprise the database of science. The scientists concentrate on creating, developing, and expanding their experiences. The data collected as building experience may be of two forms: Observable data (capable of being seen or measured) and non-observable data (relations derived from statistical probabilities) (Duschl, 1990). Based on the data collected, science learners extend their experience to understand the scientific world by collecting the observable/non-observable data and carefully observing the scientific phenomena. Thus, engagement in building experience (e.g. data, observations, phenomena, systems, objects, events) illuminates an important aspect of scientific knowledge.

B. Patterns in experiences (laws and generalizations). Scientific knowledge is also developed through our understanding of the relationships between and among experiences for finding patterns. Patten seeking in experiences is an essential scientific knowledge and practice that is extended and developed more based upon the empirical data collected and experienced (Anderson, 2003). Patterns drawn from multiple experiences contribute to the development of lawful or lawlike relationships among the data (Duschl, 1990). The development of generalizations can be also drawn from the empirical relationships. The patterns such as laws and generalization from the experiences built are primary stepladders to reduce our experience to order, as Bohr (1990) argues. This is exactly what scientists practice with massive data and experimental raw results. Science learning also occurs in similar ways, when students understand the relationship between or among data. Science learners need to find the patterns in experiences as scientists seek to find scientific laws and generalizations in their data.

C. Explanations (hypotheses, models and theories). Another type of scientific knowledge is scientific explanations that are constructed through explaining the pattern in experience. The explanation of patterns takes several forms such as scientific theories, models, and hypotheses. They take the important roles of condensing various dispersed patterns to a tidy way to make sense of the world. Scientists try to provide scientific theories and models to explain the complex and diverse patterns taken from the material world. This tells us of how scientific practice based upon science knowledge is accomplished in our efforts to scientifically reason and understand the material world by explaining patterns in experiences. This enduring process makes a contribution to scientific knowledge growth.

Scientific Practice. The key scientific practices in which I am interested are inquiry and application. Each involves connecting experiences, patterns, and explanations, but they work in different directions.

A. *Scientific Inquiry.* Scientific inquiry takes place through the process of building experiences, finding patterns in experiences in the material world based on individual observations or data, and finally constructing scientific explanation to explain patterns and experiences. Through scientific inquiry, science learners make personal sense of the scientific world, not only by extending our experience (observation and data), but also by reducing it to order to find patterns (laws, generalizations, models and theories) (e.g. Bohr, 1990).

B. *Scientific Application.* Scientific application is as important as scientific inquiry, since we consider application as a central part of science learning. Another important aspect of scientific practice, scientific application involves explaining and describing real-world examples or experiences (data, phenomena, systems, events, objects, events) using scientific models and theories, which entail explanatory process. Scientific understanding is achieved when we describe, explain, predict, or design real-world phenomena and systems in the scientific material world (Anderson, 2003). This way of fostering scientific understanding needs a conveyance of scientific application as a critical component of effective science teaching and learning, since it the scientific practice that helps science practitioners make connections between gained theories and models, and real world experiences in ways that enrich understanding of scientific concepts (Wiske, 1998).

In particular, in terms of the relationship between scientific knowledge and practice, I argue, it is crucial that the scientific practices, inquiry and application, involve making intimate connections among three major types of scientific knowledge: experiences, patterns, and explanations (Anderson, 2003; Hogan & Fisherkeller, 1996). The scientific knowledge "inseparably" constitutes scientific practice. For instance, engaging in scientific application involves explaining experiences and patterns using scientific explanations. Without elaborating on experiences, scientific explanation remains incomplete and meaningless due to the lack of connection between the real world experience and scientific explanation. Engaging in scientific inquiry involves finding patterns in experiences to construct explanation. Without either finding patterns or constructing explanations, scientific inquiry remains incomplete due to loosely relating it to experiences, data, or phenomena.

Thus, making congruent connectedness among the scientific knowledge contributes to performing scientific practice, leading to scientific understanding. With disconnected scientific knowledge, I argue that science learners must fall short of scientific understanding because it is hard to make sense of the scientific world by not seeing how the aspects of scientific knowledge are related to each other among experience, pattern, and explanations.

Patterns of engaging in scientific knowledge and practice: Sense-making strategies

Teachers make choices about ways in which to use scientific knowledge to make connections among experiences, patterns, and explanations. When teachers engage in making such connections, they demonstrate to their students the ways of engaging in scientific practice. Their modeling provides information to students about what it means to engage in the practice of science. To examine teachers' approaches to develop scientific understanding, the patterns of practice are described.

Anderson (2003) discusses these different approaches in making sense of the scientific world. They include procedural display, practical reasoning, narrative reasoning, and model-based reasoning.

A. Procedural display. Procedural display is a reasoning pattern that makes no connection among scientific knowledge and takes place for the sake of the performance for grade exchange. The teacher generates words, facts, or diagrams that are not personally meaningful to him or her, but that are what the students want for preparing for test. However, procedural display neither helps students make sense of science, nor engage in the scientific habits of mind of curiosity and rigor.

B. Practical reasoning. Practical reasoning is another sense-making strategy that the science teacher works on mostly between experience and pattern, making connections between the two back and forth. But few or no attempts are made to relate his/her experiences and patterns to scientific explanation. Thus, the teacher relies heavily on his or her local experience in an effort of understanding the world in sensible ways, making practical sense of the scientific phenomena. The practical reasoning can be understood as action oriented, person- and context-bound, tacit, integrated, and based on beliefs (van Driel, Beijaard, & Verloop, 2001).

C. Narrative reasoning. Narrative reasoning is another important reasoning strategy. Narrative reasoning takes more of a linear approach to developing and using scientific knowledge. Experience, pattern, and/or explanation is used to describe the scientific phenomena, but in a disconnected way. The stories and narratives are nicely developed around the scientific knowledge, but they are not connected to each other. Narrative can be used to explain the phenomena as a form of story that contains the story of the general facts that provide some meaningful account of how the world is. This consists of a sequence of events without rigorous causation and is frequently associated with analogies or metaphors that take a familiar and experientially real form to the practitioner. Narratives and metaphor remain important reasoning strategies for sense making of scientific world.

D. Model-based reasoning. Model-based reasoning takes place when the teacher develops an account that systematically relates observed characteristics of the scientific phenomena to a theoretical model. Unlike other sense-making strategies, model-based reasoning involves making close connections among experiences, patterns, and explanations back and forth. This reasoning strategy is used to make sense of and explain the real world examples using scientific theories, models, and hypothesis. Scientific understanding can be achieved through model-based reasoning.

Therefore, the use of the analytical framework permits me to resolve the difficulties and limitations I pointed out in the earlier research literatures for addressing my research questions in this dissertation study. The framework enables me to address the research questions more productively and effectively for several reasons. First, the framework provides me with detailed types of scientific knowledge, so that I can analyze teachers' specific scientific knowledge and practice shown both in interview and teaching practice. Second, the framework allows me to decode the detailed mechanism of how teachers' scientific knowledge is related to teachers' teaching practice and students' classroom performance in terms of looking at their developing and using the particular scientific knowledge and practice. Especially, which characteristics of scientific knowledge influence which features of teacher's classroom teaching practice can be explained based on the framework. Third, using sense-making strategies, teachers' various ways and approaches to understand science and help their students understand science are examined. Finally, to discuss whether teacher and/or students attain scientific understanding and what profound understanding of fundamental science we need to look for, the framework is used as useful criteria for me to investigate ways in which teacher and students engage in scientific knowledge and practice for making sense of science. The analytical framework allowed me to prepare for this dissertation study that developed a methodology, which I will describe in the following chapter 2.

Teachers' Views of Science

Teachers' teaching practices are closely associated with their views of science (Abd-El-Khalick, Bell, & Lederman, 1998; Lederman, 1999). I here define views of science including two aspects: ideas about favorite sense-making strategies and ideas about how to make scientific knowledge valid or legitimate while they come to understand science.

A. ***Ideas about favorite sense-making strategies.*** A teacher's view of science is related to her understanding of, and engagement of various sense-making strategies. When a teacher prefers to engage in procedural display that generates words, facts, or diagrams that are not personally meaningful to him or her, the teacher views the important aspect of science as developing factual definitions. When a teacher favors narrative reasoning, the teacher's view of science involves that scientific understanding consists of developing stories of a variety of scientific events. When a teacher prefers practical reasoning, the teacher tends to view science as building experiences to find key scientific patterns. When a teacher prefers model-based reasoning to other reasoning strategies, it shows her views that scientific practice entails explaining real world examples using the scientific models and theories.

B. ***Ideas about how to make scientific knowledge valid or legitimate.*** A teacher's view of science is related to her understanding of how learners validate scientific knowledge, while they come to understand science. When a teacher considers that valid scientific knowledge comes from authoritative sources, such as textbooks and famous scientists, the teacher's view of science includes respecting the expertise of scientists and authors. In this case, the individual learner's independent reasoning practice about the scientific phenomena tends not to be considered as developing important scientific knowledge. Rather, the teacher believes that students learn science by mastering important facts and vocabulary.

On the other hand, when a teacher considers legitimate scientific knowledge as developing personal sense-making through working with individual learners' observations and experimentation, the teacher's view of science involves developing personal meaning for data. When working with the data, teachers can also differ in their ideas about how learners work with data to develop understanding, viewing the process as primarily inductive or as hypothetico-deductive. For viewing science as inductive process, individuals' scientific understanding entails working with the data through collecting data to make sense of them and developing understanding of the empirical data. Thus, the teachers believe that students learn science by discussing, describing, and explaining patterns in experience. For viewing science as a hypothetico-deductive process, individual's scientific practice involves a process of developing data-based arguments that demonstrate the superiority of one theory or model to other hypotheses. Thus, the teachers believe that students learn science by participating in data-based arguments. This perspective is to consider arguments around opposing and conflicting opinions as an important way of validating scientific knowledge within the community. This view entails assumptions that scientific knowledge develops through arguments, debates, and negotiations between differing theories and ideas.

Overview of the Dissertation

Having provided the reader with the literature that informs this study as well as the interpretative framework through which the data will be displayed, I now turn to a brief overview of the remainder of the dissertation. Chapter 2 explains the methods and context of the research study. Chapters 3 thru 5 describe the three cases to examine the scientific knowledge and practice of three elementary teachers in three different contexts. These chapters also include data from interviews and descriptions of their classroom teaching practice, and students' classroom performance. In these chapters, I use the analytical framework to examine the scientific knowledge and practices of three elementary teachers, and their ways to make sense of the topic of condensation. And finally, in chapter 6, I conclude with a discussion of how teacher's scientific knowledge and practice are associated with teaching practice and students' classroom activities, and suggest what types of scientific knowledge and practice, and other intellectual resources elementary science teachers need to look for to support students' opportunities to learn science, and discuss the implications of this study for science teacher educators and elementary science education.

Chapter Two

Method

Study Design

This case study examines three experienced practicing elementary teachers' scientific knowledge and practice that were exhibited in three different contexts, interviews, teaching practice, and students' classroom performance. A total of 7 elementary teachers (3 interns and 4 experienced) participated in this study. Each of the teachers taught the unit of the water cycle in the fifth grade for about 5 to 8 lessons. During the unit, they taught evaporation, condensation, precipitation, and the overall water cycle. This study examined the topic of condensation, which each of the 7 teachers taught in one way or another. Among the 7 teachers, this study reports the cases of 3 experienced elementary teachers.

For data collection, prior to their teaching practice, structured interviews were administered, including a scientific knowledge interview and a pre-observation interview. During their teaching, all of their teaching practices and students' classroom performances were videotaped. The classroom observations and field notes were made in every classroom visit. After teaching practices, post-observation interviews and stimulated recall interviews took place. All of the written artifacts were collected, including lesson plans, teaching materials, classroom handouts, students' journal writings, worksheets, and assessment papers.

For data analysis, all of the audio taped interviews with the teachers were transcribed and analyzed. All of the videotaped classroom conversations and discussions between teacher and students were transcribed and analyzed through discourse analysis. Throughout the analysis, each teacher's scientific knowledge and practices were analyzed in three different contexts: interviews, teacher's teaching practice, and students' classroom performance. The characteristics of scientific knowledge and practice were compared across those three contexts.

Sample Selection

In this study, both prospective and experienced practicing elementary teachers participated. The total eight elementary teachers (four prospective and four experienced) were recruited while they were planning to teach *the Water Cycle* in Weather systems, third quarter unit in the fifth grade. The unit was taught from late January through mid March.

Four prospective elementary teachers, which I call interns, were recruited from the Michigan State University (MSU) internship program in Team 1 and 2. The interns were chosen among the volunteers who would be teaching the water cycle over their internship years in the 5^{th} grade elementary classrooms in their field placements, while taking master level methods classes in the teacher education program. Four interns were chosen, but one intern was dropped from the study before her classroom teaching. Thus, three interns remained participants in this study.

Four practicing experienced elementary teachers who had diverse teaching experiences were recruited from the city of Lansing, an industrial city of the state of Michigan. Two teachers who were considered to be good at science were purposefully chosen for this study. The recommendations from Lansing school district teachers, science specialists and faculty at MSU were considered in choosing the two best teachers in the district. They had participated in the professional development workshops partnered with the MSU teacher education program. They were enthusiastic, knowledgeable, and reform-minded teachers. The other two teachers were chosen through the regular recruitment process. The recruitment letters were sent to all of the 5th grade elementary teachers in Lansing, who were planning to teach the water cycle unit.

This intended selection process allowed me to have a wide range of elementary teachers from novice teachers to experienced teachers, and also from so called "good" practicing teachers to average or below average level teachers. By situating the range of different levels of elementary teachers in this study, I intended to examine various levels of informants who could provide this study with useful and richer research contexts, possibly including teachers' diverse backgrounds in science teaching, various teaching experiences, different preparations for teaching through different professional development experiences (e.g. reform minded teachers), and so on.

In the preliminary data analysis stage, I collected and analyzed data from all of 7 teachers. I then finally chose 3 experienced teachers who represented a range of backgrounds and approaches to science teaching in order to develop the detailed analysis and reports. The reason I did not include the interns in the final stage of this study was because during the analysis, the interns showed the inconsistent teaching practice due to their mentor teachers' inputs and influences. It was hard to keep track of what they originally intended to do and what they actually enacted, blurring the characteristics of their own knowledge and teaching practice. Their teaching practices kept shifting, as their learning to teach proceeded with their interactions with their mentor teachers.

The three informants are Diane, Sarah, and Kate. They were all veteran teachers. Diane had 35 years of teaching experience as an elementary teacher. She majored in general science. To get her teacher certificate, she took several science courses, including chemistry, biology, and general science. Diane said that she loves science and teaching science.

Sarah had 25 years of teaching experience in the elementary school. She majored in social studies. Sarah said that her favorite subject is social studies, but she also likes teaching science a lot. She took some science courses in her undergraduate, but she could not recall what they looked like.

Kate had 7 years of teaching experience as an elementary teacher. She majored in animal science and veterinary medicine. In her undergraduate program, Kate took many science content classes, including biology, organic chemistry, biochemistry, physiology, etc. She was majoring in elementary science in the master's program. Kate was still taking more science classes such as physics, geology, etc. She had actively participated in professional development workshops for elementary science teachers.

Data Collection

The data for this study were collected from 7 elementary teachers prior to, during, and after their teaching of condensation. Three sets of data were collected: Structured interviews, videotaped classroom observations of teachers' and students' activities, and collections of teachers' and students' written artifacts, prior to, during, and after the 7 teachers taught a science topic, *the Water Cycle in Weather Systems,* to fifth-grade students over about five to eight lessons. The interview instruments are attached as appendices (See Appendix A).

1. Structured interviews

Three types of interview were conducted: A scientific knowledge interview, a pre-observation interview and a post-observation interview.

Scientific knowledge interview. I interviewed the teachers to examine their scientific knowledge and practice on the water cycle that includes evaporation, condensation, precipitation, and the overall pattern of the water cycle. In the process of developing the questionnaires, I matched the science contents to *Fifth Grade Science Pacing Guide* (Lansing School District, 2002) that outlines the main teaching goals for teaching the water cycle to 5th grade students. The main objective in the guide was to explain the behavior of water in the atmosphere and to help students to understand various aspects of the water cycle in weather, including clouds or fog, precipitation, evaporating puddles, flooding, droughts, etc. Matching the interview questionnaires to the pacing guide made it possible to focus on the essential topics that the teachers needed to handle to align their curriculum and instructions suggested by the school district.

In the scientific knowledge interview, there are two types of interview questions. First, the interview questions asked what particular types of scientific knowledge and practice, including experience, pattern, explanations, inquiry, and application, teachers knew on the various topics. Second, the other part of the interview questionnaires prompted the teachers for their responses to students' ideas on the particular real world examples of various topics. The interview allowed me not only to examine their understanding and knowledge about certain scientific ideas, but also to examine their ways of handling students' diverse ideas through making instructional and curricular decisions.

Pre-observation interview. I interviewed teachers to get information about their initial ideas on planning of their lessons of the water cycle. Prior to their unit teaching, I asked questions to examine the ways in which teachers planned to establish the goal of the lesson, select the classroom activities, use the curriculum materials, employ particular instructional strategies, and assess student learning.

Post-observation interview. After their teaching practice, I conducted post-observation interviews to investigate their teaching cycle: planning, teaching, assessment, and reflection of their teaching practice. This made it possible for me to examine how they thought of the changes they had to make from the original plan, how they reflected on their teaching practice, what aspects of their teaching practice they judged to be effective, and what they thought needs to be improved next time.

As a part of post-observation interview, I also conducted stimulated recall interviews while sitting down with each of the teachers and watching the selected portion of the videotaped teaching practice together. Through the interview, I examined how they reflected their specific teaching events and performances. I asked them to think about what changes they had to make, compared to their initial intended lesson plan, and why and how those changes were necessary for them.

2. Classroom observations of teaching practice and students' classroom performance

The classroom observations were made to examine the teachers' teaching practice and students' classroom performances. I made observations of their teaching of the water cycle and took field notes. My observations focused on investigating how the teachers exhibited their scientific knowledge and practice in their classroom teaching. The classroom observation allowed me to find things that can't be captured from the interviews, including the on-going interactions and the development of dialogues between the teacher and students.

The observations particularly permitted me to find the similarities and discrepancies between their classroom teaching practice, and their scientific knowledge and understanding that they stated in the earlier interviews, and to examine the changes made between their initial plans and ideas addressed in the interviews and classroom teaching practice. I looked to see what ways the teachers enacted the planned teaching and examined how they performed their instructional ideas and scientific knowledge that they addressed in the interviews.

All of their teaching performances were videotaped. The teachers' classroom interactions and dialogues with their students were focused and recorded. The students' classroom performances were also videotaped, while students engaged in developing interactions with their teacher, discourses lead by the teachers, and reactions/responses to the teachers' teaching practice during the classroom activities. The videotaped classroom events provided me with rich information of ways in which the students of the different teachers learned the science and how they engaged in classroom discourses to make sense of the scientific world with the influence of the teachers' scientific knowledge and their teaching practice.

3. Written artifacts of teaching and learning

I collected written classroom artifacts such as lesson plans, teaching materials, work sheets, activity directions, textbook and curriculum pages, other teaching resources, pre- or post-tests sheets, teaching logs, students' journals, students' assessment papers, and examples of student work, including drawings.

In summary, the full combination of the multiple sources of data on scientific knowledge and teaching practice in teaching the water cycle allowed me to investigate the elementary teachers' scientific knowledge and practice exhibited in interviews, to examine various ways that they developed their teaching practice, and to situate the particular aspects of scientific knowledge within particular aspects of science teaching practice to help students learn to make sense of science.

Data Analysis

A qualitative ethnographic methodology is used in this case study (Erickson, 1986; Spindler & Spindler, 1992). Data analysis included extensive discourse analysis of classroom dialogues and conversations between teachers and their students. Analysis entailed examining the three occasions of the data sources, which were the audiotaped interviews, videotaped classroom teaching, and videotaped students' classroom performances. The close analysis of the transcriptions of interviews and classroom dialogues repeatedly took place. For analyzing the transcribed data, the particular qualitative data analysis software, QSR Nud*ist N5 version 1.2, was used. A coding system about scientific knowledge and practice was developed and used in data analysis, and I continued to add to and correct the coding scheme according to emerging information about the teachers' scientific knowledge and practice both in the interview and in their classroom teaching practice. For arranging and effectively managing the massive case study data, the data base software, FileMaker Pro 5.0, was also used.

In order to address my research questions, the analysis of data collected from three experienced teachers took the following 4 stages: Setting content focus, organizing the data from the three contexts, analyzing scientific knowledge and practice, and answering research questions.

1. Content focus

In this study, the content focus was condensation in the context of the topic of the water cycle unit. I particularly focused on specific experiences, patterns, and explanations of condensation that teachers and students demonstrated in interviews and classroom practices. The list of the scientific knowledge and practice is shown (see Table 1).

When I analyzed teachers' scientific knowledge, I used the particular examples and definitions of those terms. For instance, when I analyzed teachers' scientific knowledge of "*Experiences*," specific examples of "Experiences" included: The water on the outside of the iced cup, breathing on the mirror, the water on the cold pop can, the water on the cold car window pane, the water on the cold pipe, the water on the mirror in the bathroom, morning dew, fog, and individual clouds. I also focused on "*Patterns*," such as: Condensation takes place when cold objects meet warm air, Condensation occurs when moister air cools off, Condensation takes place when warm water vapor meets cold air.

Experiences (data, observations, phenomena, systems, objects, events)	**Patterns** (laws, generalizations, graphs, tables, categories)	**Explanations** (models, theories, hypotheses)
• The water on the outside of the iced cup, • Breathing on a mirror, • The water on the cold pop can, • The water on the cold car window pane, • The water on the cold pipe, • The water on the mirror in the bathroom, • Morning dew, • Fog and individual clouds.	• Condensation takes place when cold objects meet warm air, • Condensation occurs when moister air cools off, • Condensation takes place when warm water vapor meets cold air	• *Conservation of mass* – Changes of state do not change the mass or nature of a substance, • *Tracing substance with the changes of state* – the water vapor or gaseous water in the air turns into liquid water on the cold glass, without changing substances or matters. • *Heat energy transfer* – the loss of heat energy makes water vapor turn to liquid water on the glass.
→ **Inquiry**: Finding and Explaining Patterns in Experience		
← **Application**: Explaining Experiences using Explanations, Theories, Models		

Table 1. The List of Scientific Knowledge and Practice on Condensation

Especially, when I focused on "*Explanations*," I particularly examined and analyzed whether a teacher had a compatible or complete or good scientific understanding of explanation. I looked for their accurate understanding of these main theories of condensation: *Conservation of mass* – Changes of state do not change the mass or nature of a substance, *Tracing substance with the changes of state* – the water vapor or gaseous water in the air turns into liquid water on the cold glass, without changing substances or matters. *Heat energy transfer* – the loss of heat energy makes water vapor turn to liquid water on the glass.

With respect to scientific practice, I focused on "*Inquiry*," looking at how various experiences are related to one another to find patterns and how scientific explanations are constructed to explain those examples and patterns. I also focused on "*Application*," looking at how particular experiences or examples and patterns are explained based on scientific explanation.

2. Organization of the data from the three contexts

For the analysis, to analyze teachers' scientific knowledge and practice, I organized the three different sources of the data: (a) interviews, (b) teachers' teaching practices, and (c) their students' classroom performances.

From interviews, I organized and analyzed the interview data to look at how teachers met three expectations that they were supposed to consider to make sense of condensation. They include:

(a) Explaining the examples of condensation,

(b) Relating examples to other examples, and

(c) Responding to students' ideas or works.

When teachers responded to the three expectations in interviews, I examined what kinds of scientific knowledge and practice they engaged in.

To analyze the teachers' teaching practice and students' classroom performances, I organized and analyzed the classroom data around 5 classroom events that three teachers commonly exhibited in the classrooms. They included:

(a) Teachers' use of textbook materials,

(b) Observing, describing, and explaining condensation,

(c) Teachers' explanations,

(d) Using explanatory textbook reading, and

(e) Assessing students learning.

In each of the classroom events, I closely looked at how teachers' scientific knowledge used in classroom teaching was similar to or different from that which appeared in the interviews. I examined how they used their scientific knowledge to use textbook materials, help students observe, describe and explain condensation, provide the students with their explanations, help the students understand the textbook readings, and assess student understanding of condensation. I also investigated whether they were able to engage their students in scientific inquiry and application at a level appropriate for the students' understanding of condensation in every event.

From students' classroom performances, my analysis focus was particularly given to look at how the students had opportunities to learn science in the classroom activities. For doing so, I investigated the 5 classroom events listed above. In each event, I looked for what kinds of scientific knowledge and practice the students demonstrated, developed, and practiced in classroom activities with their teacher's support and teaching. I investigated to what extent and how the students' scientific knowledge and practice exhibited in the classroom performance was associated to the teacher's scientific knowledge and teaching practice. I examined whether the students were engaged in the classroom activities in ways that could support their scientific understanding of the material world through scientific practice based on the various scientific knowledge they gained.

A detailed description of how I analyzed the scientific knowledge and practice in the three contexts is followed below.

3. Analysis of scientific knowledge and practice

In the data analysis, I looked for the specific types of scientific knowledge and practice in three different contexts: (a) interviews, (b) teachers' teaching practices, and (c) their students' classroom performances. (See Appendix B) Here, I show ways in which I analyzed teachers' scientific knowledge and practice in the interview data.

From the interviews, I analyzed teachers' *Scientific Knowledge* of experience, pattern, and explanation, in the following ways, using the analytical framework laid out in Figure 1 earlier. The focus in my analysis was devoted to:

- **[Distinguishing experience, pattern, and explanation]** Examine how teachers distinguish types of knowledge on condensation, and the extent of their knowledge in each category: experience, patterns, and explanations they come up with on condensation.
- **[Experiences]** Investigate whether they can come up with examples, data, and observations on condensation, and what kinds of specific examples, data, and observations on condensation they can come up with.
- **[Patterns]** Investigate whether they can find scientific patterns in examples, data, and observations on condensation, and what kinds of specific patterns in examples, data, and observations on condensation they can find.
- **[Explanations]** Examine whether they can come up with scientific explanations on condensation, and what kinds of specific scientific explanation they can come up with.

- With students' hypothetical ideas or work, look for their thoughts and ideas of the particular examples of students' conceptions of evaporation and their ways of responding to students' various knowledge/ideas on condensation.

To examine teachers' *Scientific Practice*, I examined how the teachers made connections among scientific knowledge, how they engaged in scientific inquiry by relating their experiences of the examples of condensation to other experiences to find the scientific patterns and construct scientific explanations about how condensation works in real world situations. I also examined how they engaged in scientific application, through the use of scientific explanations to understand real world phenomena. The detailed analysis includes:

- **[Making connections]** Examining whether they can make connections among the various science knowledge through scientific practice: inquiry and application on condensation.
- **[Scientific Inquiry]** Looking for teachers' ways of engaging in scientific Inquiry, and examining whether the teachers can use the scientific examples and observations to find patterns and develop scientific explanations.
- **[Scientific Application]** Looking for teachers' ways of engaging in scientific application, and examining whether they can use the scientific explanations, theories, and models to explain the real world examples through model-based reasoning.

While analyzing teachers' scientific knowledge and practice, I looked for patterns that would indicate their sense-making strategies. My analysis included:

- Sorting the teachers' statements into different categories, and looking for qualitative patterns in the lists of their sense-making strategies.
- **[Procedural display]** Examining whether they rely on procedural display by repeating factual definitions of the science facts, showing superficial understanding of condensation, and telling the simple story of condensation.
- **[Practical reasoning]** Examining whether they have practical reasoning by accounting for scientific phenomena of condensation based on their personal experience in non-scientific life: Looking for their practice working between experiences and patterns (not with explanation).
- **[Narrative reasoning]** Examining whether they use narrative reasoning by explaining the scientific phenomena as a form of story that contains the story of the general facts, telling a sequence of event without rigorous causation, and frequently using analogies or metaphors that take a familiar and experientially real form to the teacher: Looking for their practice working on experiences, and/or patterns, and/or explanations, but in a linear way without making connection among those knowledge.
- **[Model-based reasoning]** Examining whether they perform model-based reasoning by developing an account that systematically relates observed characteristics of the scientific phenomena to a theoretical model: Making intimate connections among experiences, patterns, and explanations.
- While the teachers respond to the scenario that includes students' possible ideas and concepts, examining the types of their scientific reasoning when correcting

the students' ideas, suggesting ways to teach the students for scientific understanding.

From both teaching practice and students' classroom performance, analysis of teachers' and students' scientific knowledge and practice carefully matched the analysis that was conducted on the interview data. Teachers' and students' scientific knowledge and practice were also analyzed in the classroom context. I looked at how they distinguished and generated experience, pattern, and explanation, and how they made connections among the scientific knowledge for practicing scientific inquiry and application. I looked at what particular strategies they used for understanding condensation. The detailed descriptions of the analysis of teacher's classroom teaching practice and students' classroom performance are included in Appendix B. (See Appendix B)

4. Answering research questions

Based on the detailed analysis of scientific knowledge and practice from the data in each of the three contexts, I answered my research questions. To answer my first research question I examined specific types of teachers' scientific knowledge and practice on the topic of condensation in the interview. I then compared and contrasted the teachers' scientific knowledge and practice as it appeared in the interviews and in their teaching practice respectively. I also examined how teachers' scientific knowledge and practice, and classroom teaching practice are related to their students' classroom performance, offering students opportunities to learn science.

This made it possible for me not only to trace the relationship between teachers' scientific knowledge and teaching practices, and students' classroom learning performances, but also to clarify which characteristics of teachers' scientific knowledge influenced which aspects of their teaching practice.

Having described the methods used in this study, I now turn to the first case – the case of Diane.

Chapter Three

The Case of Diane

Overview

The first case, the case of Diane, shows how a practicing elementary teacher with limited scientific knowledge effectively managed classroom discourse to help students develop understanding of the key scientific pattern of condensation. Diane did not display extensive scientific knowledge, but she engaged in developing a practical understanding of an important scientific pattern. Both in the interview and teaching practice, Diane elaborated examples of condensation to find patterns in them through making coherent connections back and forth.

This case illustrates how elementary teachers with limited scientific knowledge and less experience in science can effectively offer students opportunities to learn science through making connection between experiences and patterns.

Diane

Scientific Knowledge and Practice shown in the Content Interview

In the interview, Diane engaged in exhibiting her ways to meet three major expectations that a science teacher is supposed to meet, while talking about her ideas about condensation. The expectations are (a) explaining the examples, (b) relating examples to other examples, and (c) responding to students' ideas or work. Thus Diane's scientific knowledge and practice are described to show how she met these three expectations in the interview.

Explaining the examples

Diane was first asked to consider what would happen to the outside of the iced cup. In explaining the phenomena of the water formation on the outside of the cup, Diane told a narrative story of how the temperature change between the cold water and the warm air affects forming water outside of the cold cup. Diane made use of "the coldness pattern" to explain why condensation takes place. To highlight the features of Diane's explanation of condensation, the portions of her talk that involve her main ideas are presented in bold.

Shinho: What would happen to the outside of an iced cup?
Diane: You're going to have all that water beads, see how this even dripping down here, it's because the temperature again is different and this is colder, meaning warm air, it's going to form rain. It'll form condensation. You're going to have beads of water all the way around that cup, on the outside.
Shinho: Why do you think that happens?
Diane: I think it's the temperature change between what's in here and what's out here.
Shinho: Temperature? Where?
Diane: The temperature on the glass now.
Shinho: Oh! on the glass.
Diane: On the glass! Because of the temperature of the liquid that's inside causes this to be colder than the outside air.

Diane focused on the temperature differences between the cold object and the warm air as the primary condition for the occurrence of condensation. In the case of pouring the hot water in the cup, Diane said that it would form steam above the cup, but no condensation on the outside. In her explanation of what causes condensation, Diane repeated the temperature condition to account for the phenomena.

Shinho: What causes the moisture outside of the cup or the vessel? You said that it depends on the temperature?

Diane: Because the temperature inside the cup is different than what it is on the outside, and when those two different temperatures meet, it's trying to bring that object or that glass up to that temperature that it is in 5 so it forms the dew drops. It forms that.

Shinho: What if we pour the hot water?

Diane: That's what I just...

Shinho: So what do you expect then?

Diane: If you put hot water in there you're going to have steam, I mean, steam is going to go up, you won't have that condensation on the outside.

Shinho: Outside?

Diane: No. It's just when it's so cold and it meets the air.

The conversations with Diane permit us to think about her theory to explain condensation. To Diane, the temperature condition was her main theory to explain the condensation on the iced cup. Her explanation of condensation was primarily based on the key pattern in the examples, cold-warm temperature difference. Yet Diane did not use other scientific theories or models to explain condensation. For instance, she did not mention tracing substances, conservation of matter, molecular model of matter, the different states of water, etc.

In the following portion of the interview, Diane compared the weight of the water from the ice melting with the weight of the ice. Diane made two apparently contradictory predictions. She said that since ice is solid, ice is heavier than the water. Diane then mentioned that as ice melts – since the weight of the solid ice gets lighter – the water would be heavier due to more water as the ice melts.

Shinho: How do you think the weight of the water from the ice melting will compare with the weight of the ice? And why?

Diane: I think, the weight of the water... the water level? Or just the weight of the water?

Shinho: The weight ... the weight of the water from the ice melting will compare with the weight of the ice.

Diane: The weight of the water is still going to be lighter than the ice, ice is heavier, it's a solid, water is lighter.

Shinho: What would happen to a balance of the iced cup as time passes by, now it's balanced on a scale, so as time passes by what will happen?
Diane: Well, there's going to be more water in here as it melts so it's going to be heavier so it's going to go down and that's going to go up.

It may be that further probing would have resolved the apparent contradictions. It is important to note, though, what Diane did *not* do: She did not invoke conservation of mass to predict that the mass would not change when the ice melted.

When Diane was further pushed to trace substances through the process of condensation, she explained the origin of the condensation on the cup based on her own speculation.

Shinho: Where do you think the moisture on the outside of the cup came from? Was it something else before it was liquid water?
Diane: Boy! What a good question! Hmm… I wasn't actually doing it. I think it was… what was it, it's in the air. It's there and it combines with that to make it, so it was… But what was it? Oxygen? Is oxygen crystallized to make that? I think… Boy! I had three kids who asked that question, what was that? What made that? The kids would ask that question.
Shinho: You said that… I'm just trying to understand… You said the air somewhere around. So can you say a little more about what you mean by the air?
Diane: I think that there's water in the air, I mean, I think that there's moisture because, you know, you can have mold on a wall that comes from just the dampness in there. So water goes into the atmosphere. It's in the air, it's around us and it's the… Then I think it is the change in temperature that makes the difference. If I put, but if I put hot water in that coffee cup, will there be condensation on the outside? But there's moisture in the air, there's moisture everywhere.

In addition to the interview about condensation, Diane responded to some questions about clouds to which she related her ideas of condensation. In the interview, Diane did not seem to relate condensation to cloud formation. Although she mentioned a lot about the condensation conditions before, Diane did not make clear how clouds could be formed. Diane began talking about clouds, by saying they "absorb" water.

Shinho: What are some things that you know about clouds?

Diane: Clouds hold water. Um... they absorb water...
Shinho: What do you mean "absorb" water?
Diane: They absorb it because when it... that's where some of the water from these puddles go, into the clouds. Um, I think clouds are formed... again, would differences in temperatures... from wind form, weather... Okay, so this, to me, there's wind up here and these are... these don't look like ones that are... Oh! You know all the different kinds of clouds that look like that?
Shinho: ...
Diane: And some are because the wind has blown through them and they're not weighted down with water that's evaporated from the, from the earth, so that... clouds have weight because of water they absorb from the earth.

In the follow-up conversation, Diane said that clouds are made of air and water.

Shinho: What do you think clouds are made out of?
Diane: I think they're made of... water, um... I think they're made of water. I think there's water in them, then. Air... they're air and water.

Thus Diane did not relate cloud formation to condensation. Diane's somewhat confused and inconsistent responses to questions focusing on mass change and tracing substances contrast sharply with her clear and consistent emphasis on the conditions—warm air coming in contact with cold objects—that cause condensation to occur. To explicate where the water came from, Diane seemed to put less value on using a substance tracing theory, such as molecular model of the matter and changes of state. Instead, the temperature condition as a key pattern was consistently called upon for her to make personal sense of condensation.

Relating examples to other examples

In the interview, Diane was able to come up with various examples and personal observations of condensation. In relating those examples to each other, Diane exhibited her understanding of the pattern in condensation that water forms when cold object meets the warm air. She named the temperature difference as the major pattern forming water on the cold surface.

> Shinho: Can you think of other times when something like this happens?
> Diane: My windshield when I…
> Shinho: What do you mean?
> Diane: **The windshield on the car, when I get in it it's sitting outside and you get in and it's going to fog up**, you have to, you may have to actually depending on the difference in the temperature have more condensation that so the windshield, I think **dew on the grass** when you go outside and you have a change in temperature, **window panes, depending on the temperature outside and inside**, you could have that same thing happening on the inside, it depends on the insulation but temperature I think on window panes.
> Shinho: Any other examples you can think of?
> Diane: I think, you know sometimes on the water faucet itself, depending on what water you're running, if you're running cold, cold water to get, you know, sometimes you want the water really cold to get a drink of water and you let the cold water run and then **the faucet actually, um, has condensation on the outside because it's so cold and then again meeting that warm temperature** that's in the room so you'll have some of that.

Diane brought up the specific examples to back up her emphasis of the temperature condition of condensation. Her personal observations and experiences involved the windshield, dew on the grass, window panes, and the water faucet. Diane related all of them to one another to find a pattern: cold object and warm air make condensation. With the example of the cold-water faucet, she stressed when condensation could happen on the faucet. Diane said that running cold water in the faucet would make condensation when the faucet is in a warm room.

Responding to students' ideas or work

In the interview, Diane demonstrated how she would respond to five different students' ideas about condensation. In her response, Diane showed three characteristics of teacher response to the students' ideas: (1) her evaluation (more content centered), (2) her description of students' thinking (more students centered), and (3) her response with her justification (more socially oriented). My initial expectation of her responses to the five students' ideas was that she would follow this order, answering with her evaluation first and then move on to the other two agendas.

Interestingly, however, Diane often started off her response with her justification to each student's idea. She responded to them in a way that would nurture a socially comfortable classroom environment. When probed more by me, she then provided her description of the students' thinking, and then offered her evaluation based on her science content understanding.

The first student's idea that the iced cup is sweating was presented to Diane. Diane did not seem to be satisfied with a word, "sweating." She kept saying that she would ask Jane to tell her more about her thinking about sweating.

> Shinho: And how would you respond to the students' ideas and what would you tell them about their ideas? So the first student, Jane, is saying that the iced cup is sweating. How would you respond?
>
> Diane: The ice is sweating? "Tell me more."
>
> Shinho: The iced cup is sweating.
>
> Diane: **That's what I would tell Janie. "Tell me more." "Tell me more what you're thinking." It's just sweating? What would make it sweat?**
>
> Shinho: Okay. So we would be thinking about your own thought and idea, how do you think? How do you think about Jane's idea?
>
> Diane: I actually think that she really is going from personal experience. I get hot, I sweat, water comes out. I mean that's where she's... that's the level, very basic that an ice cube is like me, it's in a cup, it's hot, it sweats.
>
> Shinho: So would you like to consider her answer would be fine or acceptable?
>
> Diane: I think that that in an essence tells me, what is she, first grade?
>
> Shinho: 5th grade.
>
> Diane: **Oh, she's 5th grade, cause that to me is really very limited background or knowledge though.** I would want her ... I guess what I would want from that exchange is that she ventured a chance to guess. That's just what my thinking is.

Diane went on to discuss how she might use examples to explain the difference between sweating and condensation.

> Shinho: What if Jane observed this iced cup and she again repeated, "Oh! See? The cup is sweating."
> Diane: Okay, but if that's what she got from this, then I need to change and do something other than this cup and the ice in a cup. I would want to **talk about what about dew**, you know, have you ever been out, someone, you get up in the morning and the grass is kind of wet. Have you been on a football field? Take her to other examples of that. Have you been in your car and your mom has that, I mean there's actually **fog that forms on the window shill.**
> Shinho: What if she is still saying "Oh! The window is sweating"?
> **Diane: People sweat, objects don't. But pipes sweat and that maybe an experience that they've had, pipes do sweat, objects do sweat. Something gets too cold and the temperature is... and you've gone in your basement, you've gone there, it's dripping.**

In trying to define what "sweating" means, though, she added in the temperature conditions of condensation again. With the example of a cold pipe, however, Diane ended up having difficulty distinguishing sweating from condensation. It is noteworthy that Diane did not make a substance-tracing distinction between sweating and condensation—sweat comes from inside the body while condensation comes from water vapor in the air.

Given the second student Paul's idea, the water comes from inside of the cup, Diane responded that since there is no hole in the cup, the water can't come from inside or leak out. In this case Diane did make a substance-tracing distinction. Diane said that the water on the cup "really comes from outside of the cup," not from inside.

> Shinho: Paul is saying that the water outside of the cup comes from inside of the cup.
> Diane: There's no hole in there, so you're thinking that the water's leaking out? Actually it's not, let's wipe it off and see. Let's look for that. Again that sends limited exposure to the concept, I want to take them to another kinds of activities that would expose them to what is the terminology that I want them to use, what is it that's going to bring me to the point where they know that that's condensation and then what's going to happen to condensation.

And as they say it's sweating or it's leaking, it's coming from inside, and you, some things are just directly stated, you just simply say that is, that didn't come from inside, that really comes from outside the cup, now what do you think?

Next, Diane responded to the hypothetical case of Mary, who suggested that water on the cup formed from hydrogen and oxygen in the air.

Shinho: So the next student, Mary, is thinking that hydrogen and oxygen in the air are water on the cup.
Diane: That's what she says? This is hydrogen and oxygen, that have come in contact with the cold cup and it forms water. Doesn't it?
Shinho: So what do you think?
Diane: **I think that that would be acceptable.**
Shinho: Okay, because?
Diane: Those are two components that come together to form water.

In her response to Mary, Diane added the temperature condition, "have come in contact with the *cold* cup." Then she said that that idea "would be acceptable." Again, Diane showed that she was concerned much about the conditions of condensation, cold object forms condensation.

When she was given Carl's idea, the water in the air moves to the outside of the iced cup, Diane did not accept Carl's idea as a complete one.

Shinho: Carl is saying that the water in the air moves to the outside of the iced cup. What do you think about that?
Diane: That, that water in the atmosphere...
Shinho: Water in the air moves to the outside of the iced cup.
Diane: So that's... you... this air is collecting, this water, this cup is pulling water out of the air and it's settling here on the cup? I'm still going to have to go with exposure, exposure, exposure, and terminology. Where is this water coming from? **So I have this bottle and it may be cold and we see that and we talk about that. Okay, I'm going to put another cup. Here's another cup. It doesn't have ice in it,** so how long would I have to leave that cup sitting there, and this is classic, and that's, oh let's get a glass up here, it's the same thing. It's sitting here. It has no ice inside, what's going on?
Shinho: So do you think his idea is acceptable?
Diane: I think that, I think that... all of those ideas are acceptable because I do want them to at least thing. I would want to explore with them and present them with several more options of how could water have gotten on here, let

me explore with them the things that they said. Okay it's leaking. Well, do you think there are holes, is there a cup, what? You think this is, um, the terminology's sweating. Then what? It depends, maybe their dad's a plumber and they've heard of sweating pipes.

Shinho: What if he keeps holding the incorrect ideas, even after exploring.

Diane: Even after direct, okay exploring is fine but then I think you come to a point where you just directly tell them with, okay, now you've got three different things happening, what is actually happening here is "condensation is forming on this cup."

Shinho: Yeah, okay.

Diane: And that comes from, so you directly teach them what it is.

By contrasting the iced cup with no iced cup, for instance, Diane seemed to indicate that the important thing is the ice in the cup making it cold. She was less interested in tracing matter to keep track of the water between the air and the outside of the cup. For her, though, water that forms in these particular conditions should be called condensation.

With Joe's idea of evaporating and condensing on the cup, Diane finally said that his idea is great and that's actually what happens. For the first time in the interview, she related the condensation on the cup to the larger-scale patterns of evaporation and condensation in the water cycle.

Shinho: Joe is saying that water is evaporating from the water on the cup and condensing on the outside of the cup.

Diane: That the water's going up, it's evaporating, and then it's condensing here on the outside, okay. That's acceptable.

Shinho: How would you tell him?

Diane: That's great and that's what happens in the ocean, the ocean is evaporating up and we're having condensation over here, we're having rain, or it depends on what's happening, it's going up into the clouds and then it's going to come down.

Commentary on Diane's Scientific Knowledge and Practice in the Interview

The interview with Diane consistently focused on a key pattern: the temperature condition of condensation, cold object and warm air make condensation. Diane elaborated the key scientific pattern in experiences, making connections between experiences and patterns.

In contrast, Diane was inconsistent and not always successful when the questions focused on tracing substances and conservation of matter. Diane did not often use model-based scientific ideas, such as conservation of mass, changes of state, and molecular theory. Her primary narrative for understanding condensation was "when cold objects meet warm air, condensation forms" or "warm air contacting the cold causes condensation."

In her responses to students' ideas, Diane was concerned about whether students understand the conditions for condensation. As far as students' ideas met "the cold object-warm air" conditions, Diane was satisfied with their responses. Further, throughout the conversation with Diane, her pedagogical ways to consider students' ideas or work were revealed. She showed a consistent concern for understanding how the students were thinking and never simply labeled a student's response as incorrect. This way of managing students' ideas played a significant role in her teaching practice and students' learning activities, as described in the following section. It is very interesting to see how Diane organized classroom discourse to effectively maintain the desirable learning community at the same time that she successfully achieved her goal of teaching the important scientific pattern to the students.

Teaching Practice and Students' Learning Activities

Diane devoted a total of two class lessons to teach condensation along with another topic, evaporation. She set up three different investigations, as laid out in the textbook. They were evaporation in the saucer pan, evaporation in four shallow dishes with different conditions, and condensation on an iced cup. Diane's teaching practice was informed by her intimate knowledge of the textbook materials. Therefore, the nature of textbook she relied on is first described below.

Diane's Teaching and Textbook Material

To understand Diane's way of organizing her teaching practice, it is particularly useful to pay close attention to the nature of the textbook materials that she used, since Diane's teaching practice seemed to be closely related to her use of the BSCS textbook. (See Appendix C – Analysis of activities in the textbook). When Diane taught the water cycle in weather systems in 5th grade, she relied heavily on modules in the BSCS Science T.R.A.C.S. (1999) that the school district adopted as the "reform oriented" inquiry-based text. Diane closely followed the guidelines and recommendations, as suggested by the Teacher's Edition in BSCS.

Overall Features of BSCS text. "5th grade BSCS: Investigating weather systems" emphasizes the features of science learning (See BSCS teacher guide pp 3-6), particularly organizing science content and classroom activities around the 5Es instructional model. 5Es instructional model sequences the learning experiences for students: Engage, Explore, Explain, Elaborate, Evaluate. The features in BSCS are "standards-based (NSES and Benchmarks for science literacy guided the development of the curriculum framework), constructing understanding and active learning (the program emphasizes high-interest, developmentally-appropriate activities that are related to students' lives), collaborative learning, and assessing understanding and abilities. BSCS particularly "places primary emphasis on scientific inquiry, involving students in both structured inquiry and independent inquiry (See page 13)." BSCS claims to divide the inquiry outcomes into two types, developing students' "abilities" necessary to do scientific inquiry and developing their "understandings" about scientific inquiry.

Intended Goals for 5 Lessons. Given the overall goal in the BSCS textbook, the 5 class sessions about the water cycle were allocated within "*Lesson 6: What drives the weather?*" According to the BSCS module overview (see BSCS teacher's guide page 18 and 109), they intended that Lesson 6 would focus on "Explore and Explanation" states in the 5E model.

The specific purposes of the lessons were "to introduce the water cycle and the information of clouds from the condensation of water vapor and to help students understand that the Sun is the source of energy for all weather phenomena on Earth's surface." The lesson was designed to have students perform simple evaporation and condensation activities at home to explore the ways water changes state from liquid to gas and vice versa. The overall expected outcomes relevant to the water cycle (on page 110-111) were that "students recognize that water continuously evaporates from Earth's surface and condenses in the atmosphere in a pattern known as the water cycle," "students use simple equipment and tools to gather data and extend the senses," and "students communicate investigations and explanations."

Diane's Teaching and Textbook. Given these general goals suggested in textbook, Diane followed guidelines reflecting the goals in each lesson activity. For instance, in lesson 2 in the BSCS textbook, the teacher guide recommends not to try to have all students' ideas and reach consensus. "*Do not expect all students to agree and do not take time now to come to any consensus. This is the time to get all ideas "out on the table" so that students can question their reasoning and possibly their results. They will discuss these ideas throughout the lesson* (BSCS teacher's guide page 115)."

BSCS intended teachers to nurture students' scientific reasoning by allowing them to think about various ideas instead of telling them correct answers or scientific ideas. So, the textbook assumed that the creation of a "disagreement" with one another would be a useful teaching strategy for possibly facilitating cognitive conflicts. The particular recommended strategies were: "*Rather than getting reports from many students, ask one student to report and then ask if anyone has anything different to report or anything to add*"; "*do not expect all students to agree and do not take time to come to any consensus* (See teacher's guide page 115)."

Thus, given the BSCS textbook's intention to address Explore and Explain states, Diane's teaching went thoroughly over part of the 5E model sequence, following each step and suggestion offered by the Teacher's Edition. As the guidebook recommends, Diane took a position to provide students the opportunity to engage in investigations, observe the cold iced cup, take journal notes, and describe what they observed, rather than promptly responding to all of students' questions or ideas and telling them what to do and how to do it.

Observing, Describing, and Explaining Observations

In the first class, after spending a bit of class time giving students general orientation and explanation of how and what to do, including safety checking, Diane asked students to carefully look in their textbooks for directions to complete the three investigations by themselves. These investigations were the saucer pan, evaporation in four shallow dishes with different conditions, and condensation on an iced cup. As the textbook focused more on "Explore and Explain" stages in the 5E model, Diane encouraged students to work with the data in the investigations, rather than taking a lead herself in the classroom activities. The students were asked to carefully read and exactly follow the steps for the investigations, as directed in the textbook. While the students were engaged in the activities, she moved around the classroom to check the students' progress on the three investigations, two evaporation activities and one condensation.

For the condensation activity, in particular, Diane asked the students to make observations of the cold iced cup on the table, as directed in the textbook. While observing the cup, the students were not yet supposed to talk in their small groups and present their findings and observations with their peers. They were rather asked to make observations of the investigations by themselves and then write down the answers to the textbook questions in their journals.

Before making their observations, students were particularly asked to jot down their predictions (guesses) of what would happen to the iced cup. Most students included their guesses in their journals. Their descriptions varied: The ice will melt (5 students), The water level will rise (2), It will become a liquid (1), It will sweat (1), The cup will have water on it in the outside (1), Water evaporates on the jar (1), and The water is going to show up on the outside (1). Many of the students did not write down their predications in their journals. But Diane did not check what kinds of prediction the students made. The students were not offered a chance to think about whether their predictions were correct or not during the class.

At the early stage of the unit, Diane rarely responded to the students' questions or ideas. There were times when the students wanted to address their ideas or observation directly to Diane, but she emphasized the importance of writing down their observations instead of talking to others. Diane often repeated saying, "Write that down! Remember?" "Write that down, because you're learning from one another, and today I really wanted you to record your thinking," or "Put that in your journal. Write it!"

Rather than directly providing students with explanation of condensation during the classroom discussion and investigations, she often asked questions and checked if the students were doing the investigations correctly, if they were making observations and taking notes in journals. She guided them to take steps during the investigations that they were supposed to complete based on the textbook guides.

> (Students were looking at two iced glasses sitting on the table.)
> Diane: So this is your glass?
> S1: Yeah.
> Diane: And you're noticing what's happening with it? This one has been sitting here longer. Do you notice any difference in that one from yours?
> S1: Yeah, ... when ... because... The melt ice, when the ice melts, it goes up.
> S2: It goes up!
> Diane: Hmm... (No further responses to students' answers.)

Interestingly, the iced cups on the table were overflowing the water all over the glass, after Diane asked them to put more ice in the cup. But neither students nor Diane tried to correctly set up the investigation of the iced cup for precise observation of what was happening on the iced cup. Rather, the class let the situation be. All three small groups had the same situation. Only one student in the whole class noticed that happening and tried to report this to Diane.

> (The water was flowing over the cup and soaking the paper towel)
> **S3: Oh, it's overflowing… We had too much ice in there (Looking at and talking to Diane)**
> S4: Yep.
> **Diane: (Diane not responding to S3's remark) … So you filled the glass with ice and water?**
> S3: Yeah.
> Diane: And you put your time down at what time you put that in, you're observing and recording what happens to the outside of the cup?
> S3: We already did that.

But, for some reason Diane did not take notice and just moved on. Instead, Diane asked students to complete their journal questions in more procedural ways. Following the conversation with S3, Diane still did not respond to her question. She only checked if the students correctly recorded the observation time and answered the questions in their journals.

> Diane: And it did, so you don't have to do it. (Reading a question in the student (S3)'s textbook, pointing with her finger) "Think about what you've observed and then answer these questions in your journal," all right?
> S3: What do you mean, "leak"? There's no hole in it.
> S4: … Like did it all … overflow? Or … (Pointing the side of the cup) Did it come from the side?
> S5: You don't do number one?
> **Diane: Yeah, you did number one, it's the doing, and then number two is what you're responding to now, all right? And I think at this time, you can do that back at your seat, because I'm going to have another group come back and set up another one. No, I want it to sit there because note the time right now and see what happens in fifteen minutes when we're getting ready to change again.**

At the beginning of the unit, Diane was consistently asking students to focus right on the task and complete their observations instead of commenting or answering their questions. This form of practice at the early stage of her unit teaching seemed to match pretty well to the BSCS text intended goals for the lessons.

In the next lesson, Diane engaged students in bringing up their experiences, observations, and data gained from last class, which was on the Explore and Explain stage in the 5E model. Diane gave students chances to share what they observed and experienced from the investigation of the iced cold cup. She began the class by saying, "I want you to share what you observed." Diane kept asking questions like "So, what happened?" or "tell us what you did."

> Diane: So you've seen that out in the world. Okay, the last experiment with the ice. Tell me what happened there, someone from there that did that. Chris, I see your hand.
> C: We put the ice in there.
> Diane: In where? Tell us what you did.
> C: Okay, we put some water in a cup, put ice in it, and set it out and it started evaporating or whatever, going away, and the ice would melt, and Gabby said how about some hot water, because it didn't tell what kind, and she put hot water and it was still cold. It was hot in there, but the ice made it all cold, and it was evaporating in there.
> Diane: Oh ~

Through the discussion, the students brought in their personal descriptions and words. Despite some of their incorrect terms or ideas, Diane did not attempt to correct students' ideas or imprecise descriptions on the activities. For most of the discussion, Diane often took a stance to listen to the students' observations and descriptions of what they did. She either repeated what the students said or summarized them back to the students. By describing what they did and observed, students seemed to be engaged in the Explore state in the 5E model by speculating on the phenomena, describing them in their own words, and interpreting them based on their own ideas and beliefs. The students' responses were consistent with the 5E strategy.

However, the students' descriptions of the iced cup were often inaccurate. They described the iced cup as "steam was coming up from the iced cup," "the iced water gets higher," "sweating," "evaporating from the iced cup," "leaking at the bottom." and so on.

In spite of students' imprecise observations and descriptions, there were many occasions that Diane did not try to correct students' incorrect ideas, descriptions, or non-scientific language. Diane led classroom discussion for students to be able to describe their observations. It makes pedagogical sense for Diane not to correct their language at that point. (Based on her point of view, the students were expressing the pattern—cold causes condensation—pretty well.)

Nevertheless , there were interesting moments in the dialogues between Diane and students. After she listened to several students' observations, Diane built on students' ideas about condensation to tell them her main ideas, which were related to her main condition and pattern that she addressed in the interview over and over again.

For instance, she repeated "slippery on the outside?" When a student said condensation, Diane immediately picked up and repeated that word. So she was making sure that when this lesson is all done, students remember condensation. With Alyssa's presentation, Diane was also repeating and using the term sweat as opposed to condensation. She repeated what the students said again. But she was making a point that sweating is not as desirable as condensation.

Chris: And the outside, steam was coming up like, you know how it was slippery on the outside? That's how it was on outside.
Diane: Okay, so it was slippery on the outside? Dennis, what are you thinking on that? What was that on the outside?
Dennis: The cup on the inside, it was full of water, we put the water with ice, it was getting colder on the inside, and so it was starting to make water on the outside.
Diane: Okay, that's what you saw.
Alyssa: I think it was condensation.
Diane: Okay, why don't you listen and then if you want to respond to that, so you were saying there was condensation on the cup?
Alyssa: I thought condensation was when it was like ... a warm thing and a cold thing and they meet and ... like sweat.
Diane: And they come together and you get, she's using the term "sweat."

Diane: Okay, Jordan, do you want to share with all of us? I think it might be beneficial. Do you want to share with all of us what you're thinking? Oh, okay, I noticed that Montrell was listening, so I thought maybe you had something to share with all of us. No?

J: No.

While students presented their ideas and descriptions of the cold iced cup, Diane continued restating and revisiting what the students had said, showing procedural responses to most of the students' ideas.

Diane: I see you. And I'm going to come back to you.

S1: I thought that the glass that had the water and the ice in it, when Gabby put the hot water in it, but it's still going to work because the ice, it's kind of like frozen water, and it will melt and it gets higher. Well, it takes longer when you put cold water, but it will work when you put hot, it still works. It will melt the ice.

Diane: Oh, I'm wondering what works? What works, the ice melts?

S1: Yeah.

Diane: I'm going to come back to what Alyssa said about condensation, that cold, when cold hits warm, you have condensation that forms on the cup? So that's ... that's settling out.

Alyssa: Like when we did it, we had the two here when we did the cloud formation.

Diane: When we did the cloud formation, so again it's temperature changing that makes condensation, that makes even clouds.

In particular, Diane came back to what Alyssa said about condensation. And she repeated Alyssa's points again. "... That cold, when cold hits warm, you have condensation that forms on the cup? So that's ... that's settling out." But it is noticeable that that was not exactly what Alyssa said. This was what Diane wanted students to remember. Diane said "Oh! Alyssa said the good idea." She seemed to make Alyssa feel good about it. But this was really Diane's idea that she wanted to tell them. She skillfully modified and changed them slightly by adding some important ideas, and told the students back with her own explanation based on their original ideas and terms. So she seemed to repeat what the students said, but her talk included several important changes and additions.

Diane was "*re-voicing*" students' ideas in order to tell them back with what she wanted them to know. It seems that Diane's working strategy was to let the students express their observations in their own words while drawing their attention to the observations and language that support her pattern. Diane was very skillful in "re-voicing" students' ideas by putting their ideas into the slightly different ones that conveyed the main scientific pattern, which was "cold object-warm air cause condensation." By effectively engaging in the practice of "*re-voicing*," she not only built on the students' words, terms, and ideas, but she also primarily gave the students her explanation of the examples.

In doing so, Diane was doing what the BSCS exactly recommends through listening to students' ideas. But she was listening in a very active way that encourages everybody to talk. When she had something positive to say, she clearly expressed it to everybody. When the students said something that was not very useful or relevant to her purposes, then she gave a procedural response. She then responded, "That is a good description you are observing," "Oh! You are recording what you observe. That is good. That is good." But when she figured out that she had gotten the important idea that she wanted, then she did not give the procedural response anymore. Instead, she gave a substantive response to the class.

Diane also wanted to connect back to clouds. She wanted to make sure that the students got the right pattern for the observations they made. Here, she switched over to another example to say the same pattern applies here. But up to this point, Diane was not telling them anything. In fact, she was shaping the conversation in such a way that the students could get a message out of it.

The dialogues in response to Alyssa's idea also prove that Diane understood condensation as a form of matter itself, not a process, because she said, "condensation that forms on the cup ... so that's ... that's settling out." There were several other occasions when Diane also showed that she considered condensation as stuff or matter on the cup. For instance, Diane continued to follow dialogues, backing up this claim. She said, "after you take a shower and you look at the mirror, there's condensation on the mirror," "So it's even colder than the condensation that she sees it's just a foggy film, but you're saying that it's gone from the foggy film all the way to ice."

After the lesson, I examined students' journals to see how they answered the textbook questions (3 out of a total of 5 questions). However, most of the students did not complete all of the questions. Fifteen students' journals were collected after class. Many students omitted writing things about this investigation. Only 7 students wrote anything down about the condensation portion. About question 1, "Did your cup leak?" 6 students answered, "The cup did leak." About question 2, "Where did the water on the outside of the cup come from?" there were 3 students, answering respectively, "The water came from the inside of the cup (1)," "It came from the coldness on the outside (1)," "The water came from the ice (1)." About question 3, "Does this investigation have anything to do with clouds? Explain what you think," only 2 students answered "No" with different reasons: "because the clouds are outside and we did the experiment inside, because we didn't use clouds."

Later, Diane did not give the students any comments on these answers. Thus, the students did not have any chance to get Diane's feedback or checks if they were working all right in answering the questions during or after class. Although many students ended up with the incorrect answer and many of them did not even answer the questions in their journal, they did not have chances to get Diane's feedback or have classroom discussion until the end of the unit.

Taking Teacher's Explanations

During the classroom teaching, Diane did not provide students with much of her explanation of condensation. In spite of her less frequent involvement in explanation about condensation and other content, there were three major occasions where Diane was involved in offering the students her explanations of condensation in one way or another.

Firstly, when students described and explained their observations of the iced cup to the whole class, Diane was engaged in explaining condensation. In doing so, as described in above section, Diane relied primarily on "re-voicing" students' ideas to convey what she believed to be the most important pattern of condensation. Through the process of re-voicing students' words, ideas, works, or descriptions, Diane effectively informed students of what conditions and patterns would be important for them to know from the various examples of condensation.

Secondly, when the class was reading the informational BSCS text about the individual stage of the water cycle, Diane's role was very minimal in helping students understand the substantive content. The text includes the macroscopic as well as microscopic (molecular level) ideas about water existing in the atmosphere in three different states of matter: Solid, liquid, and gas. The class kept reading the text about the detailed scientific explanation on how water can change from one state to another, despite the fact that the 5^{th} graders could easily have been confused with the advanced reading level of the text.

Interestingly, though, given the detailed scientific theories in the text reading, Diane neither explained the molecular level of changes of states, nor even mentioned about the particular content written in the text. As a consequence, students had many chances to learn Diane's major pattern and explanation about the scientific pattern, but they had less chance to think about other working scientific explanations, such as states of changes, molecular changes, and heat energy transfer. More detailed descriptions of the classroom activities based on the class's use of the textbook are discussed in the next section.

Finally, Diane primarily used the "*re-voicing*" strategy again to help students make connections among the various examples to find the major pattern. For instance, at the very end of the second class, Diane guided students to list other examples of condensation, which is the Elaboration phase in the 5E model as suggested in the BSCS text.

> Diane: I want us to take a look at other situations when you've seen evaporation and condensation. Now that we've read exactly what it is, we saw it in the investigations; we've been able to evaluate it, as we've looked at all those weather words you did a fabulous job with. Now I want to know what are other situations where you've seen evaporation or when you've seen condensation. ...
>
> S2: Like condensation, like when you take a shower, on the mirror, it's usually like covered with steam.
>
> **Diane: Oh, he said after you take a shower and you look at the mirror, there's condensation on the mirror. That's a great example. What else, Clarissa, and then one with Jessica.**

Given Diane's directed guidance, the students were able to come up with various examples. In doing so, Diane again showed a skillful job of "*re-voicing*" to draw students' attention to the relevant examples and then to make sure the students saw the pattern that ties the examples together successfully. Through the process of re-voicing, Diane carefully informed students of what conditions and pattern would be important for them to learn from those various examples of condensation. At the very end of this lesson, Diane also engaged in considering other types of examples, "warm object meets the cold object," that the students brought up. She did not come up with these examples before in the content interview.

S1: Um, I have another example. When I'm in the car, it's really cold, like this morning it was really cold, and my mom turned on the heat, and I think the heat combined with the coldness that was already there, it made the steam on the window.
Diane: Oh, so on the windows, and you have to use the defroster hopefully so you could see out of it, but that's a great example, like the mirror one. Jessica.
J: There's this one, mine just has ice in the windows, that's what my mom told me, but like when, sometimes I touch it and I see steam and I can write on it.
Diane: So it's even colder than the condensation that she sees it's just a foggy film, but you're saying that it's gone from the foggy film all the way to ice. Great example. Any others? ...
Diane: So we've got the foggy mirror in the shower, we've got the window in the car, any others?

Here, to Lindsey's question, Diane was not clear how clouds are formed. Just like Diane mentioned in the content interview, she showed her understanding of clouds being made of gaseous water, saying "It's air vapor!" instead of correctly explaining "It's liquid water or condensed water."

Diane: Lindsey.
L: Like you're outside and you breathe the cold air, and when you breathe the warm air, what is it?
Diane: Um, it's vapor, air vapor! You're saying is that like the cloud?
L: Yeah, it's like smoke.
Diane: Smoke? Is that the same?
S1: We could see if it was cold enough in here.
Diane: (showing a gesture of blowing off in the air) **I'm not seeing it. It's not that cold, fortunately, okay? So, we have to have that cool surface, the warm air hit the cool surface to have the condensation happen.** So, I want us to now just take a look at the role of the sun in all of this, you've come to some of that, we've read the solid, the liquid, and the gas.

Again, Diane continued doing a careful job of adding in her main point to satisfy the conditions of condensation, showing her knowledge of condensation. But, it is also interesting that Diane seemed to reject "seeing the breath" without a cold surface as an example of condensation.

Diane worked hard to make students understand that condensation has to do with the temperature condition and change between cold and warm. She wanted to teach the students the main condition/cause of condensation over and over again, by explicitly telling the class what expected prevalent pattern and condition of condensation they would need to know. Until the very end of the class, however, given those various examples of condensation, Diane did not exhibit her interest to teach students what kind of "*substance tracing*" can be happening to explain the examples of condensation more than addressing the cold conditions of condensation. Thus, Diane demonstrated that she provided the students with lots of opportunities to make connections between examples of condensation and scientific patterns, but not with scientific explanation, though.

Use of Textbook's Explanatory Reading

Later in the second lesson, Diane engaged the whole class in reading the informational text together about the different states of water, the role of the Sun, and cloud facts. She relied on the textbook reading so that students could read together as a whole class and gain the scientific language and information about condensation, evaporation, precipitation, and the overall water cycle.

But Diane's role in explaining the scientific ideas presented in the text was very minor. While reading the text together, Diane gave students few additional explanations about the scientific ideas. After the students read each paragraph of the text, Diane often engaged in procedurally reacting to what the text explains, by just checking if the students got some of the information, instead of engaging the students in learning more about the substantive content including the detailed scientific explanations around the topic of molecular changes of state.

> Diane: Jordan, will you begin reading water solid, liquid, and gas?
> J: (reading textbook loudly) "Water exists in the atmosphere in three different states of matter: solid, liquid, and gas. Water in a solid state is snow and ice and hail. Water in a liquid state is rain and the droplets that make up clouds. Water in a gaseous state is water vapor."
> **Diane: A lot of information! Mary, you are next.**
> M: (continue to reading the textbook) "Water can change easily from one state to another. Liquid water can freeze and become solid. Solid water can melt and become liquid water. Liquid water can evaporate and become water vapor. Water vapor can condense and become liquid water or solid ice."
> **Diane: Condense! That word is what we are talking about.**
> Diane: Mandy?
> M: (continue to read the textbook) "What causes these changes? You already know that you need to add heat to solid water, ice, to make it melt into liquid water."
> **Diane: And solid water is what?**
> S1: Ice!
> **Diane: Yeah!**

As we can see here, even with quite dense reading with lots of scientific explanations, Diane did not follow up with her elaboration or clarification of what those readings actually mean. She did not attempt to provide students with a detailed explanation of condensation, as also shown below.

> M: (continue to read the textbook) "Did you know that your freezer works by taking the heat away? When there is less heat, the temperature decreases and liquid water inside the freezer freezes into ice cubes. Adding or taking away heat energy is an important factor in changing water from one state to another."
> **Diane: Excellent. Now Lindsey? How does heat energy?**
> L: (continue to read the textbook) "How does heat energy help evaporation and condensation? Liquid water is made up of many molecules moving around. When heat is removed from liquid water, it can be cooled so far that the molecules stop moving around. They lock together in a pattern and liquid becomes solid. The opposite is also true. When heat is added to liquid water,

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the molecules of water begin to move faster and faster. Some reach the surface of the water and escape into the air. These molecules evaporate."

Diane: Jennifer?

J: (continue to read the textbook) "As long as the air is warm enough to keep the molecules moving, water will stay in the air as water vapor, but if the air touches a cooler surface and cools down, the air cannot hold as much water vapor. The air releases the extra water in the form of droplets on the cold surface. The water vapor condenses."

Diane: Condenses, it does!

From the reading of the text, Diane showed that she was concerned about a word, condensation, not paying attention to other information addressed in the textbook. She was more concerned that the class was learning about a word "condense" from the textbook. But she was not concerned much about other information relevant to substance tracing. Diane was not interested in addressing molecules or where the matter comes from or conservation of mass, things that are substantially relevant to scientific explanation. Even when the class read a long paragraph about molecules of matter and movements and changes of matter, she did not point out any of the issues or ideas to develop a further discussion about them. Diane did not provide any further explanation more than the textbook information gives. Although there were some ideas related to molecular theories and models that possibly students had difficulty understanding, she did not consider any more scaffolding to support students' understanding, which could possibly result from her pedagogical decision along with her adoption of the 5E model in the textbook sequence.

Students ended up reading the textbook information loudly for about 20 minutes without having time to discuss the meaning. The class kept moving on to next lines and pages for reading through about 5 pages of compacted informational text.

Assessing Students' Understanding

Diane assessed students' understanding twice, before and after the unit, through pre-test and post-test. For both tests, the students were asked to draw the diagram of the water cycle. In the diagram, they were asked to include three labels: evaporation, condensation, and precipitation; objects (ocean, clouds, puddle, lake, and rain); and the directional arrows. Other than that, they were neither asked to include any other scientific words or terms related to each process, nor asked to explain the meaning of each word or stage.

In the pre-test, 13 out of 22 students drew the diagram without being able to label any stage of the diagram. Some of them included examples of each step. Eight students included only one label, evaporation. Only one student drew the diagram with the three labels. In the post-test, 3 out of 20 students drew the diagram without labeling the stages. Nine students included the partial labels in the diagrams without fully completing the labeling. Eight students were able to draw the diagram with the full labeling.

Students were therefore assessed mostly about their factual knowledge, including the nominal labels of the three stages of the water cycle and the objects around the environment. However, they were not assessed about what kinds of examples they could find in each element of the water cycle, including evaporation, condensation, and precipitation; what kinds of scientific pattern they could find in the various examples in each step of the water cycle; and how they could explain the process of changing the water among various stages.

Therefore, despite Diane's coherent efforts to convey to students the major scientific pattern of condensation throughout the unit, it was impossible to evaluate whether or not the students attained scientific understanding of the process of the water cycle.

Commentary on Diane's Teaching Practice and Students' Learning Activities

In her classroom teaching practice, Diane consistently emphasized the major conditions of condensation, "cold object-warm air make condensation," which is the important scientific pattern in condensation. Diane kept addressing a major scientific pattern across the several lessons in a coherent way to teach the main condition of condensation, rigorously helping students understand the important aspect of scientific knowledge and practice of finding key scientific pattern in various examples. This certainly indicates that Diane was always looking for the main point to get across in her classroom teaching for students' learning. But, Diane did not make use of other scientific explanations, such as substance tracing, changes of state, and molecular theory.

This way of engaging in her teaching practice echoes her scientific knowledge expressed in the content interview. As exhibited in the interview, Diane seemed to focus more on seeking a scientific pattern in various examples rather than considering scientific explanation. Therefore, Diane was quite successful at telling the story through narrative and practical reasoning about the conditions necessary for condensation to take place.

Diane's choice of teaching strategy reflected her views of science that science is comprised of working on data to make personal sense of the examples through taking the process of tuning the personal ideas. Diane was very skillful at "*re-voicing*" students' ideas by putting their ideas into the slightly different ones that she wanted to tell the students. By effectively engaging in the practice of re-voicing, she not only built on the students' words, terms, and ideas, but also gave the students her explanation of the examples.

With Diane's support, students were able to discuss how to make condensation happen. After coming up with various examples of condensation at the end of the second lesson, the students were able to find the scientific pattern in those examples, which was "cold object and warm air make condensation." Therefore, by the end of the unit, the students had chances to engage in reasoning about a scientific pattern across the examples, although they did not have much chance to move to another level of understanding about substance tracing theory along with other scientific explanations, such as the states of change, molecular theory, and heat energy transfer.

In the students' written work, though, without Diane's support and lead most students did not do a good job completing the journal writing, and elaborating and refining their thinking through writing. Many of the students often skipped writing their predictions, descriptions, and answers to the textbook questions. Since Diane did not give the students any comments or feedbacks on their written work, the students' written ideas and descriptions were left not considered.

Reflection in Post-Observation Interview

In the post-observation interview, Diane had a chance to reflect on what scientific knowledge and practice constitute good teaching practice of the water cycle, including condensation. Diane said that she did not know a lot and could know more about the water cycle. But she also said that teachers do not have to try to know everything.

> Shinho: So what do you think about your own science knowledge to teach the water cycle? Do you think your own science knowledge would constitute your good practice, good teaching of the water cycle?

Diane: I think… I think I could know a lot more but I think that that's important because I think the students also respond to the teacher's comfort level and if you are comfortable in what you're presenting and you're presenting it, not heavy-handedly, but if you're presenting it in a matter of look at this information and do you know this? And what else do you know? So I do think it is important that you, if you don't really know, because I guess I don't. I think teachers need to know where to accumulate knowledge, where to get the information, how to direct students to it. If you're going to teach something, if you go on the internet and get all the information you need the day before, you get the book, but I think I don't want teachers to walk out thinking that I have to know everything about everything because I don't want students to have that because now they're just changing and that's what you want teachers to view their job as, not that I have all the answers.

In particular, though, Diane mentioned that she would need to learn particularly more about clouds, which are related to condensation.

Shinho: In teaching the water cycle to your students, what do you wish you tried more of and why?

Diane: Oh I think the clouds, I think that's fascinating and just the whole cloud formation, I think, um, that was a, um, there were, well… there were good facts in the book about, I mean, cloud facts and they were, um, interesting and I think that's an area I would have liked more information on or been able to give them more information because I think the clouds really do give us a lot of indicators of weather and what's going on and how critical they are in the whole cycle, so that would be the area that I want more information, more knowledge on.

Given Diane's speculation about her knowledge for teaching the water cycle, I specifically followed up with a question of whether she knew the particular examples of condensation at the time of which she already finished her teaching. Diane was able to list a variety of the examples of condensation. This indicates that even if she did not know all of the scientific theories and explanations, Diane understood the particular examples of condensation well.

Shinho: Then how about then your thinking, your own idea for next time or something, so can you actually come up with some examples, on condensation for example.

Diane: On condensation, when we talked about, no because I think, when I checked off my list and I looked at this and the kids listed every single one of these, I'm thinking Josh talked about it on the, um, in the shower, um, that, um, Jessica talked about it, um, on the car window. Someone else talked about it on the car window but Jessica took it a step further, no, because then I could actually draw, you know, if it's cold, I can get the rain. Someone else talked about the dew. Every single one of the examples are ones that I was prepared to give, but I thought it was more powerful because the students came up with every one of those, but those are the ones that I was prepared to give for them in terms of, um, dew, I mean, I'm thinking Lindsey or, I came out and the sled was there and there was water in it and it was solid, it was frozen and then we got in the car and this happened, um, so on the car windows you could see where water vapor was, so…

Shinho: So how did you use their examples, their real world examples that they came up with in class?

Diane: I think I used them in, that was their response to the actual question and that was my direction and guiding, great, that's exactly what I wanted to hear. My, I even may have said to some, I think you looked them up in the book, I think you got all those examples right from there to actually say these are things I want you to know, this is what I wanted you to recognize, you brought those out.

In watching a video clip of her teaching in class, Diane and I found that she did not respond to one student's idea during the classroom discussion on evaporation and condensation. Diane was asked why she did not provide the student with her feedback. Diane said that the reason why she did not quickly respond to him was that she did not try to "direct their thinking."

Shinho: So what was at that time, what was the important thing you tried to do in that moment?

Diane: In that moment I really wanted them to think of the experiment but I wanted them to grasp that evaporation was happening in the one dish, and that condensation was happening in the other, and as scientists we discuss those things among one another but we listen to what the other person is saying in that we're able to build off of that. But they didn't, they actually said what they had to say, and okay, I said what I had to say.

Shinho: So one, I remember one student actually made a comment that the water is trying to escape from the dish, but I thought that you didn't respond to his comment carefully and then you were just done.

Diane: Yeah. I think it was Trevor, yeah.

Shinho: So what do you think? So how can you actually do it next time if you had that similar situation?

Diane: Well I think… because, again, as this group I wasn't trying to direct their thinking and the same way, I didn't show them the model of the smoke box first because I think that that's part of the learning in it, but I think that…

The following exchange helped me understand some ways in which Diane taught condensation through her responses to, and interaction with students' ideas, employing "Re-voicing" teaching strategy. Diane explained her rationales for why she encouraged students to bring in their personal observations and experiences of condensation primarily, rather than her telling the students the right answer or explanation, or remedying students' incorrect ideas. Diane put a great value in her teaching for "Making her students feel comfortable in her class." For her, making science class a "socially safe place" was a high priority in teaching condensation.

Shinho: What may be possible for you to achieve those goal, objectives?

Diane: You know, I have to think… classroom atmosphere. I think the students feel a comfort level of taking risk, that it wasn't like, oh if I say the wrong thing that anyone was hesitant to give their thinking, they wanted to go a step further to make sure I heard their thinking, so I didn't, you know, and sometimes you get that sense of fear, right or wrong, but hands were going up, even when I was trying to stop the discussion, that was an indicator to me because they, could you just take one more, well wait a minute, we're up to almost, well what about this, and then even after, even during lunch, comments and the students say Mrs. Brown you didn't hear what I was saying when I was saying that or you didn't listen or you didn't this or you didn't call on me. Where they actually want you to know that I've that I've thought about this and you know we were checking that off.

Shinho: What would be the important factor to create that atmosphere in your classroom?

Diane: I think it starts with… listening to them and validating for them that you're listening to them, and it's okay, and to be able to gently correct or strongly correct depending on the student, you need to let them know that's right and you're headed in the right direction, that's good. I appreciate you sharing your thinking and not that's not right or that's not wrong, I do think it's body language as well as what they hear you say but they also watch you and how you're responding to them, are you interested in it, are you positioning yourself so that you are listening?

Here, Diane was clearly stating that not correcting students' language or ideas immediately was her conscious strategy and intentional decision. For her, the most important issue in her class was to respect students' ideas in order to create a responsive environment to share everybody's ideas, even if their ideas were incorrect. This consolidates her intention of "not directing students' thinking,"

To teach condensation effectively based on her value of creating safe classroom space, Diane seems to take a sort of "constructivist" teaching stance. She wanted to take a role as a facilitator rather than delivering the factual information or answers to the classroom. Given this purpose, Diane practiced carrying out her goal of being a facilitator to encourage students to come up with their ideas and discuss with others about condensation.

> Shinho: What was your role as a teacher you would like to take?
>
> Diane: I think my style is more, um, facilitator, I'm there to facilitate the knowledge and not to just dump information, I've got all of this and I have books and I can just, um, spew out all this information but I think as a facilitator, I really aimed to direct and to guide and to make sure that, and I don't know in many cases if it's just a straight right or a wrong, but a way that I want to guide their thinking and I want to inspire them to go further, to love science and to see that they have knowledge and it builds on things that they've heard in the past, that they've done in other grades, and how it all fits together and how they'll continue to think like that. I want some of them to be inventors, to be scientists that figure out cures to things that, you know, maybe they'll go up in space, they'll investigate other planets, other life forms, maybe, um, they'll figure out how we can best utilize our environments and our plants and our water and that kind of thing. So I really want to facilitate learning and I want them to see themselves as scientists and see themselves as learners.

In the pre- and post-observation interviews, Diane talked about and implied her view of science that turned out to be closely associated with her choice of teaching strategy and classroom teaching practice. In the following exchanges, Diane showed her views that scientific knowledge emerges from personal experience through inductively working with data.

Diane's teaching was to engage students in various hands-on activities and investigations to collect data and make observation of the particular scientific events. Diane saw her science teaching as providing the students with lots of opportunities to look at, observe, collect, and measure various things. In the pre-observation interview, Diane talked about her general feature of her classroom activities.

> I think that it's going to be two fold, it's going to take some research and it's going to take some experimentation. I think that as I looked, overall in the book, looking at boiling water, putting, because I don't have windows in here but we've found some other places, I've located some other places that are in close proximity where they'll do some measuring, some couple of things that we've already, that we're going to look at that just deals with when moisture… one of them is the same thing, we're just going to fill your measuring cups and set them in places and I'm going to let the kids determine what places they want to set them in as they journey the building, so we'll look inside and there may be some sunny windows in here, there may be some shaded areas and then this is, this they're going to follow it for, um, three days and the water's in the sun, the water's in the shade, so they're actually going to watch that and that's going to develop some other questions and then for me. … The kids will measure how much water they've put in and then they're going to monitor that, what happens, but the thing that, in using this even, um, they're estimating from which measuring cup do you think the water will evaporate quicker? In the shade or in the sun and then they're just going to check, they're going to measure it, they'll pour it out and see how much water is left in there, they know how much they'll start with…

Diane seemed to think that building experiences with the data is important for students to understand science. Diane said that science is full of hands-on observations and activities that motivate students to engage in science class. Compared to other subject areas, she mentioned that it was easier to manage science classrooms because of lots of interesting hands-on activities that the students could be engaged in, as shown in the post-observation interview.

> Because it (science) is so hands-on or specific observation or actually doing something that the management of it is easier than other subject areas, and that's what I'm saying, I like the fact that they have just a smattering of information so it's not a lot of lecture but I want to be able to draw it and correctly pull out what they're thinking and then tell them what I'm thinking or what the correct thing is, if it's correct. Science has enough things that are open to investigation and that's what I want them to learn.

Diane emphasized using lots of scientific instruments and tools for students to gather data. She wanted the students to be able to know how to use the basic instruments by being "familiar" to them.

> Shinho: What were particular activities' examples and materials you emphasized in the teaching of the water cycle? What were they and why did you choose them and how did you like to do it?
>
> Diane: Well you know, I think they were materials that the students were familiar with or had heard, certainly they know about a thermometer and although they were intrigued with that, and just simply finding out, well what is the weather like outside, what is the temperature? The rain gauge, which became a problem because it's made of glass and I never would have made it of glass, they dropped it and broke it, we had to figure out how are we going to keep the water in here? The wind gauge, the direction, just those things to monitor weather information that they weren't familiar with and they're common things so then they looked at well we don't have a thermometer outside, you can just look at it on the weather, and I said well someone has to be familiar with it and they're recording that and recording that too, um, making sure that they could read and use those instruments.

Diane showed that experience and data collection are important to her in order to understand science. To Diane, therefore, doing and learning science meant to build personal experience to understand the scientific pattern by engaging in personal sense-making through working with the data and examples of the scientific world.

Conclusion

I argue that this case presents an elementary teacher with limited and incomplete scientific knowledge who was able to successfully ensure that her students attained a particular type of scientific understanding. She accomplished this through elaborating examples to seek a scientific pattern by making connections among different examples.

Diane developed and practiced narrative and practical reasoning in both her personal scientific knowledge and practice, and in her teaching practice. Despite her lack of reliance on model-based reasoning with substance tracing, Diane was pretty successful in teaching students how to scientifically reason to find the core scientific pattern in condensation, echoing her scientific knowledge and practice shown in the interview.

In the interview, Diane demonstrated her scientific knowledge focusing less on model-based reasoning about tracing substances, conservation of matter, and change of states, but focusing more on narrative and practical reasoning about the key conditions that cause condensation. Her primary narrative for understanding condensation was "when cold objects meet warm air, condensation forms" or "warm air contacting the cold causes condensation." This was her theory as well as main point of condensation that was repeatedly addressed through the whole interview. In her responses to students' ideas, Diane was concerned much about whether students understood the primary condition of condensation and whether the students' ideas were appropriately treated in a more socially comfortable mode.

In the teaching practice and students' learning activities, Diane continued to address the scientific pattern across the several lessons in a coherent way, demonstrating the intimate association with her scientific knowledge shown in the interview. Throughout her classroom teaching, Diane aspired to make sure that students "*get*" the main point of condensation, "the coldness factor." In doing so, Diane's discourse strategy played an important role to convey to students the narratives of condensation effectively. She was skillful at managing classroom discourse by "*re-voicing*" students' ideas to help the students make personal sense of the scientific examples and pattern, which reflected her views of science.

Diane's re-voicing strategy seemed to be related to her view of science. She viewed science as the process of personal sense-making through experience with the multiple scientific phenomena or activities. Thus, when she provided her explanation about condensation, she chose the re-voicing strategy, which allowed her to value the students' ideas while also allowing her to help the students make sense of the important scientific pattern of condensation.

As a consequence, Diane's re-voicing strategy and view of science seemed quite influential on shaping students' opportunities to learn, since the students were effectively engaged in developing a scientific account of the key scientific pattern of condensation. Students engaged in developing a scientific account of the core pattern of condensation. Therefore, this case illuminates what scientific knowledge and pedagogical skills elementary teachers with limited scientific knowledge and content understanding need to consider in order to create opportunities for students' learning to make sense of science.

The next case, the case of Sarah, shows how an elementary teacher with a wide range of scientific knowledge engaged students in developing sketchy and shallow understanding of condensation without elaborating the pattern in examples of condensation. These two cases, Diane and Sarah, illustrate the contrast between one teacher with incomplete but deep scientific knowledge and the other teacher with a wide range of scientific knowledge with less elaboration with specific examples and scientific pattern.

Chapter Four

The Case of Sarah

Overview

The second case, the case of Sarah, illustrates a veteran elementary teacher, who "*covered*" a wide range of scientific terms and theories, but often exhibited sketchy understanding of some ideas of condensation. Rather than elaborating and relating the examples of condensation to find a key scientific pattern, in contrast to the case of Diane, Sarah looked for the scientific terms and theories to explain condensation, but demonstrated a lack of rigor in making clear sense of the words she used both in the interview and teaching practice.

This case demonstrates how an elementary teacher with sketchy, shallow, and incompatible understanding of a wide range of scientific topics could lead to students' learning opportunities that did not engage them in making sense of the scientific phenomena.

Sarah

Scientific Knowledge and Practice shown in the Content Interview

In the interview, Sarah described her way of meeting three major expectations and roles as a science teacher, while talking about her ideas about condensation: (a) explaining the examples of condensation, (b) relating examples to other examples, and (c) responding to students' ideas or work. The following anecdote illustrates her scientific knowledge and practice by showing how she met these three expectations in the interview. To highlight the features of Sarah's explanations of condensation, the portions of her talk that involve her main ideas are presented in bold.

Explaining the Examples

Sarah was first asked to think about a real world example: What would happen to the ice inside the cup and why?

> Shinho: This is the iced cup. What do you think will happen to the ice inside the cup and why?
> Sarah: The ice will melt. **Because the water is warmer than the ice and the warmth gives up its heat because heat travels from warm to cold and will cause the ice to melt.**

Sarah used the theory of heat energy transfer to explain the phenomena of ice melting with "heat travel" from the warmer matter to the colder. Sarah was then asked to compare the weight of the water from the ice melting with the weight of the ice, she mentioned about the volume of the melting water rather than directly answering about what would happen to the weight.

> Shinho: How do you think the weight of the water from the ice melting will compare with the weight of the ice, and why?
> Sarah: Well, the water's going to weigh… I would think that when you melt the water in the ice, the ice is going, **the volume is going to increase because as melting … water melts, as ice melts, it has to take up space, and so it's going to increase** the…
> Shinho: The weight?
> Sarah: **The level of the water**.
> Shinho: Okay.

Sarah showed her confusion about the volume change between the ice and the water, because the volume would increase as the ice melts by taking up more space.

Since Sarah answered only about the level of the water, not about the weight, another question was used to probe what Sarah really thought about the weight.

Sarah was asked to look at a drawing of a balance with an iced cup and explain what would happen to the balance.

Shinho: What would happen to a balance with the iced cup as time passes by? Like this drawing (showing a drawing of a balance with the iced cup), it is balanced now with the iced cup, so as time passes by, what do you think will happen?

Sarah: It's a good question... if it's balanced now, I wouldn't think, if you've got the same amount of weight in it then even as the ice melts it's not going to change its weight. **I would think that if it's got the ice in it and you've got it weighted out now and it's equal, that the amount that's put in there is not going to change. The weight will remain pretty much the same.**

Shinho: Because?

Sarah: Because if you've got equal weights on this one and you put the ice in and its equaled out, when it's got the iced cubes already in it, they're not going to change their weight when they melt.

Shinho: Even though the ice will be melted?

Sarah: Even the ice will be melted, if you've got the weight even here and you put the ice in it, this is going to be your weight. Maybe I'm wrong but that's the way it would seem to me.

Shinho: Okay.

Sarah: I'll have to try that one and see.

Sarah's accounts for the melting ice inside of the cup showed that she made use of the theories, such as conservation of mass and heat energy transfer. Although she made an incorrect explanation of the volume change, by saying that melting water would take more volume than the ice, her overall perception of the weight change in the ice water was in accordance with the correct scientific knowledge.

When I asked Sarah to think about what would happen to the outside of the iced cup, she used a word, condensation, to explain that when it is cold and cool, water droplets are formed as the air settles on the cup.

Shinho: What would happen to the outside of an iced cup?

Sarah: **It's going to have condensation on it because it's cold and as the air settles on it and it's cooled, it's going to form water droplets.**
Shinho: What do you mean by condensation?
Sarah: Well, **the vapor in the air is going to turn into water droplets along the side.**

Sarah referred to the temperature condition; the cold object and the air make condensation. Sarah seemed to understand the scientific pattern of condensation, which is the same pattern that Diane also developed.

It is also noticeable that Sarah defined condensation as "the vapor in the air is going to turn into water droplets along the side." She seemed to engage in tracing substances between the air and the water droplets. However, it was not clear what kinds of "vapor" she considered to turn into water droplets. The following exchange helps us see how she understood substance tracing and the changes of state.

With a question, where the moisture on the outside of the cup came from, I probed Sarah to explain how she traced substances between the different states.

Shinho: Where do you think the moisture on the outside of the cup came from?
Sarah: **It came from the gases in the air.**
Shinho: In the air?
Sarah: **The air around us... our environment is air, so it takes hydrogen and oxygen to make water, so I suppose that they've evaporated into the air at one time and as the molecules of the gas settle on the outside, they're pulled together to form the water droplets.**
Shinho: Was it something else before it was liquid water?
Sarah: The ice was a solid.

In this exchange, Sarah does not seem clear about how the matter changes its state from gas to liquid. Sarah shows that she was engaged in tracing substances, but indicated that she was not able to make distinctions among gases, hydrogen, and oxygen from water vapor. To describe how the water droplets are formed on the outside of the cup, Sarah used and listed a variety of the scientific terms, but had a sketchy understanding of those terms as well as the scientific theories, such as the changes of state and substance tracing. Thus, Sarah used the changes of state without clear understanding of substance tracing. For instance, her explanations did not include accurate accounts of how the gaseous water in the air turns into the liquid water on the iced cup, conserving the same substances or matters.

Sarah explained the process of condensation based on the molecular notions at the microscopic level. It seems that she thought that the water formed on the cup is not the same water in the air. Sarah knew that to form the water droplets on the cup, some "gases" would need to be somehow involved in making the water. However, her understanding of where the water droplets came from was left unclear and incomplete in spite of her use of another term, molecules.

So far, Sarah has demonstrated that she used and listed a wide range of scientific terms to explain condensation. But she did not show her good understanding of scientific explanations or theories.

In order to see how Sarah, based on her incomplete and sketchy understanding of condensation, would explain a phenomenon such as formation of clouds, I engaged in further exchanges.

> Shinho: What do you think clouds are made of?
> Sarah: **Clouds are made of evaporated water.** Clouds also have dust particles and things that they pick up as they move through the air.
> Shinho: Can you clarify states of water? Which ones are there and which ones do you see?
> Sarah: The only one I can see right away would be... **the light fluffy clouds would be the gaseous part** and then the heavy clouds, where they're starting to cool and come lower to the earth have not reached capacity yet to come to the earth as rain, but the moisture's beginning to get closer, I mean it's beginning to come, it's going to become moisture if the atmosphere continues at that place.

In this exchange, Sarah seemed to think that clouds were made up of "evaporated water." Sarah clarified the meaning of "evaporated water" by saying that some clouds are made of "the gaseous part" of the water. This conversation thus shows her unclear understanding of the process of condensation in the confusion of what is involved in, affirming that she did not have a clear sense of the changes of state, as described above.

In the following exchange, Sarah showed that she was not able to make a precise connection between condensation and the making of clouds.

> Shinho: In general, water has some different states, changes of state, so can you tell me what state you can think of for the different states of water?
> Sarah: In the air?
> Shinho: Yeah, around the air.
> Sarah: What we have… we would have fog… rain… is that what you're talking about, the states of matter?
> Shinho: Yeah.
> Sarah: **Those would be the liquid form. Dew. For the gaseous form, it would be the air that's surrounding us, the clouds. If we went to the North Pole, we'd have water as a solid in the ice caps. So we've got solid, liquid and gas. I think I've got all three of them.**

Here, she seemed to think in a way she was relating her experience with some scientific ideas. She seemed to make use of her experience and relate it with ideas that she has, no matter how imperfect: The dew does appear liquid and clouds do appear as smoky and gaseous to her eyes. In the discussion of how clouds form, Sarah showed that she knew clouds are made of gaseous water, making no relation to condensation.

Overall, in contrast to Diane, Sarah relied frequently on using scientific terms. Given her ambiguous uses of the scientific terms, including gas, vapor, molecules, etc., Sarah's understanding of condensation seemed to be somewhat confused and unclear. Sarah seemed to reason the examples of condensation based on substance tracing. She traced substances as well as energy. However, her substance tracing turned out to be incomplete due to her unclear understanding of how the phenomenon actually happens.

Thus, despite her frequent uses of the scientific terms and theories, Sarah did not seem to connect the scientific theories and vocabularies with her experiences, making no connections among experiences, patterns, and explanation. She exhibited difficulties explaining in what detailed process condensation actually takes place and how substances could be traced in the different states. Her broad and wide, but superficial use of the scientific language demonstrates her lack of clear understanding of scientific explanation of condensation. In her explanation of the examples of condensation, therefore, Sarah did not go beyond displaying and listing the scientific words and ideas without unpacking and explicating the meaning of them, showing her sketchy and incomplete understanding of condensation.

Relating Example to Other Examples

When Sarah was asked to come up with detailed examples of condensation, she was able to list several examples.

> Shinho: Can you think of other times when something like this happens?
> Sarah: Well, **when you set iced tea out in the summertime, uh, when we take milk out of the refrigerator and set it on the counter, uh, when we have things in the bag that we're taking home from the store that are really cold, if it's warm we have condensation on the outside. Ice cream... pop.**

The examples she brought up included the iced tea, cold milk out of the refrigerator, cold bag from the store, ice cream, and pop. Sarah listed the same type of example – the cold objects in the warm air. This shows her adequate understanding of a pattern in the various examples in condensation, just as Diane did. Sarah further extended the same types of examples.

> Sarah: Water on the outside of our windows in the winter time, **when it's really warm on the inside and it's cool on the outside and we breathe against the window or we put our nose against the window to look outside, we've got condensation,** that would be in... in their world. When they drink their colas from their glasses or bottles and they're holding it in their hand and they can feel the water, I mean, the water, it's condensing.

Sarah added water on the outside of the windows, breathing against window, putting nose against the window, and feeling water from bottles of cold colas. In relating those examples to each other, Sarah seemed to understand the cold temperature condition as a key scientific pattern of condensation, cold object and the warm air make condensation.

Responding to students' ideas or work

In the interview, Sarah was given five scenarios of students' telling various ideas about condensation. Sarah described how she would respond to the students' ideas or work. Her responses involved three features of teacher's ways of responding to the students' ideas: (1) her evaluation (more content centered), (2) her description of students' thinking (more student centered), and (3) her response with her justification (socially oriented). With the five students' ideas, I expected her to follow the order of responding to them, starting with her evaluation about students' content understanding, then moving to other two agenda involving student centered and social aspects of responses.

At the beginning of her response to the first student's, Jane, idea, Sarah started off her response with her justification to the student's idea, concerning how she would socially react to the students' ideas. Sarah's justification was that all kinds of students' ideas could be "acceptable." This shows that Sarah seemed to concern more about her respect of students' different ideas rather than putting them down or trying to correct them. Once probed more by me, she then provided her description of the students' thinking, and finally offered her content centered evaluation about condensation. The following exchanges between Sarah and me show how she made a shift from a socially oriented way of responding to content centered evaluation.

With the first student Jane's idea, the iced cup is sweating, Sarah mentioned that student's use of the term, sweating, would be acceptable in her classroom.

> Shinho: How would you respond to the particular students' ideas? What would you tell them about their ideas? The first student, Jane, is saying that the iced cup is sweating.
>
> Sarah: Well, **technically in her, at her age, it probably is sweating because when they're outside playing and their bodies are hot, they're giving up moisture and the air's going to cool the moisture on her body and that's the same thing it's doing on the glass. It's the same process except it's just different factors putting in to come up with the moisture.**
>
> Shinho: So how would you actually tell her?
>
> Sarah: **I would think it would be acceptable** and I think to draw the two together she would be able to understand more about the process.
>
> Shinho: What if she's still saying that the cup is leaking next time, because there's some water outside.
>
> Sarah: Well, then I would say let's see if we can find some holes in this cup. Let's see if it's really leaking. It might have a fine crack in it. Let's see if that's a plausible idea.

After a short justification of Jane's idea, Sarah made a content oriented response. But she was incorrectly citing the similarities between sweating and condensation that make this an acceptable response. Sarah said that sweating and condensation have "the same process" of forming the moisture on the outside of the cup, even if there are different factors involved in both situations. However, with the follow-up idea, the cup is leaking, Sarah did not accept the idea. Rather, she said, "let's find some holes in this cup," showing that she was not satisfied with the idea of leaking. Whereas Sarah accepted the term, sweating, to describe the iced cup, she did not take in the term, leaking.

With Paul's idea, the water coming from inside of the cup, Sarah basically disagreed with his idea.

> Shinho: Next student, Paul is saying that the water outside of the cup comes from inside of the cup.
>
> Sarah: Okay… again we'd have to have some kind of osmosis if the glass is solid, we'd have to have some process for the glass to get from the outside, you know, **is it going to climb up over the side to get down on the sides or is, do you think that that's really what's happening?** If you think about everything that we have here, we have a solid glass, we put water in it, we put ice in it. We could go back and think **what happened to the water before we put the ice in it? What happened to the glass?** What state of… **what was happening on that side of the glass before we put the ice in**? Now, knowing that, **would you think that it's coming from the outside, from the inside to the outside and again is it plausible, could it really happen?**

Sarah suggested some questions she could ask for students to think about Paul's idea. Sarah seemed to use these questions to help the students find ways to correct their ideas: the water coming from inside of the cup. When I pushed her more to evaluate Paul's idea,

> Shinho: So, I'm just wondering if we as elementary teachers can think about his idea as right or wrong?
>
> Sarah: **When I'm teaching science, I tell them that there are no right or wrong answers until we get through the investigation. We do an awful lot of investigation and we accept, I accept any answer, you know, until we investigate and we find the real answer.**

Instead of telling her science content relevant evaluation, Sarah emphasized that she would accept any kinds of students' answers until she would find the real answer with the students.

Given Carl's idea, the water in the air moves to the outside of the cup, Sarah began showing her content centered evaluation rather than socially responding to students' ideas, since I had pushed her to show her content centered evaluation on two previous students ideas, Jane and Paul, as shown above.

> Shinho: Carl is saying that the water in the air moves to the outside of the iced cup.
>
> Sarah: **I would tell him that his answer was acceptable, because we are surrounded by air. And if our environment is air, where else could the air have come from?**

Here, Sarah went directly into her response of how she would tell Carl whether or not his idea is acceptable, by making a judgment about his idea. Sarah's response to Carl's idea seems to be commensurate with her explanation of the examples in condensation. She said that Carl's idea is acceptable, because the air is the only matter surrounding us. Although I asked her with the question of the movement of "the water in the air," Sarah did not answer what happens to "the water." Instead, she responded that "the air" is involved, saying that there is nothing else existing outside except the air. However, Sarah was pretty vague in her use of the word, air. She did not make clear what kinds of air make this process happen and how this process happens, again showing her unclear idea of substance tracing.

As is also shown in her explanation of condensation above, her vague use of the scientific terms continued. This reminds me of the exchange with her about her explanation of condensation. For instance, when she explained the examples of condensation, Sarah used vague vocabularies, such as air, gas, vapor, oxygen and hydrogen, without differentiating or elaborating the meaning of each of them. Sarah's response to Carl's idea also demonstrated that Sarah was able to use the scientific terms with unclear and sketchy understanding of the terms and the detailed process of tracing substance.

With Mary's idea, hydrogen and oxygen in the air are water on the cup, Sarah seemed to be satisfied with the idea.

> Shinho: Mary is saying that hydrogen and oxygen in the air are water on the cup.
> Sarah: Well… **a scientist tells us that hydrogen and oxygen make the water so if you've got water, you have to have hydrogen and oxygen. … Because there's no other way to have it.**

She said that that is the only way to have the water on the cup. Sarah said that the two elements, hydrogen and oxygen, need to "*make*" the water on the cup. Sarah seemed to know that the water consists of hydrogen and oxygen, so to form the water on the cold cup, hydrogen and oxygen have to be also involved in the process of condensation. However, Sarah did not seem to really understand the changes of state. She seemed to think that the water in the air is the different substance from the water on the cup, since she mentioned that the two elements would need to "*make*" water to get on the cup. Sarah was unclear about how liquid water could be formed on the cold cup.

To Joe's idea, water is evaporating inside and condensing outside of the iced cup, Sarah basically agreed, by saying that the water is evaporating in the cup and goes up.

> Shinho: Joe is saying that water is evaporating from the water in the cup and condensing on the outside of the cup.
> Sarah: Okay. The water in the cup is evaporating, but it's not just… it's going up and being taken into all the air in the room and it's like a fan that circulates the air. **It's not the exact air that comes out of the cup that's getting to the sides of the glass, it's the air that moves in convection currents, of course I wouldn't say convection currents, but moves, like the fan, and then as any air that's drawn to it will turn to water, not just the air that was in the cup.**

Sarah was able to differentiate the water in the cup and the water on the outside of the cup. She seemed to think that water on both sides is not necessarily the same water.

However, Sarah's explanation and choice of the words for the explanation are interesting. Rather than saying that the water (or the water vapor) evaporated from the inside is different from the one outside, she used the term, the air, describing that the air on the inside of the cup is the different one from the one outside. Again, Sarah kept using "the air" to explain how condensation occurs, without making clear what kinds of air she was referring to. Thus, Sarah did not differentiate between the water vapor and the air or gases, which is the important indicator of conceptual understanding of condensation.

Overall, given Sarah's recurring use of "the air," "gas," or "vapor" instead of "the water vapor," it seems that Sarah did not have an accurate understanding of the process of condensation, which involves substance tracing and the changes of state. Her persistent choice of the term, the air, was not complete to precisely describe the process of condensation. In responding to students' various ideas, despite her frequent use of the scientific vocabularies, such as "the air," "convection current," or "vapor," Sarah did not seem to make personal sense of them. Instead, Sarah threw out a wide range of imprecise scientific languages, displaying her shallow understanding of the scientific ideas.

Commentary on Sarah's Scientific Knowledge and Practice in the Interview

In the interview, Sarah demonstrated about the similar understanding as Diane did. Sarah demonstrated listing experiences and finding a pattern in examples. She also showed that she could use a number of scientific terms, but not in ways that showed mastery of the underlying concepts. Despite Sarah's recurrent uses of the scientific terms, she often exhibited difficulties in making sense of some of the terms to explain her experience.

Sarah and Diane show a striking contrast. Although she understood a key scientific pattern, Sarah rarely used the pattern to make sense of condensation when explaining the examples. In contrast, Diane relied heavily on the scientific pattern instead of theories and vocabulary. Sarah relied a lot on a variety of scientific terms instead of a scientific pattern, without actually making clear sense of the words, including gas, vapor, molecules, etc. Her explanation of condensation involved the changes of state without substance tracing.

In her response to students' ideas, Sarah continued to display a variety of scientific terms in order to evaluate, describe, and justify students' diverse ideas. Sarah often vaguely used terms such as air, gas, vapor, oxygen and hydrogen, without carefully differentiating and elaborating each of the terms. Sarah demonstrated a lack of complete and detailed scientific accounts of how the substances could be transformed between the gas and liquid, making it hard for her to make accurate connections among scientific knowledge.

Teaching Practice and Students' Learning Activities

Sarah taught condensation for about two class lessons among a total of 7 lessons spent for teaching the water cycle. In her classroom teaching practice, like Diane, Sarah followed the sequence of activities and contents of BSCS textbook. She used the informational text as well as textbook questions to guide students to engage in activities and learning. But Sarah exhibited significant differences in her teaching practice from Diane's teaching, through demonstrating less rigor on using the intended curriculum materials and concentrating more on expanding the accurate definitions of the scientific terms. The features of Sarah's teaching practice are described in detail. The first section begins to describe Sarah's use of textbook in her classroom teaching.

Sarah's Teaching and Textbook Material

Sarah used modules in BSCS Science T.R.A.C.S. (1999) that the school district adopted as the "reform oriented" inquiry-based text. This was the same textbook that Diane used in her classroom. Like Diane, Sarah followed the sequence of activities and investigations of BSCS textbook. She also used the informational reading as well as textbook questions to guide students to engage in various activities and learning.

However, unlike Diane, Sarah did not use the detailed guidelines or suggestions that BSCS textbook specially offered to teachers through the Teachers' Edition. In pre-observation interview, Sarah addressed how she considered the textbook and teachers' edition in her science teaching.

> **I think they're pretty good, especially for a beginning teacher. The more you teach, the more you can add to it, but everything is just, in these books, you know some of it's very... um... primary. Some of it**

> **you can skip over as you go through, especially, you know, my kids have already had the liquids, solids, and gases, so we won't spend a great deal of time on that whereas a new teacher that's doing the book in order, I mean it's listed there, if they would just follow the teaching guides they aren't going to mess up and they're going to get everything that the curriculum sets down for them and everything** ... that they need to know. Probably, what I like to do is I always add and I've got charts and posters of the clouds and the weather and those will go up on the bulletin board too, within the next couple days. If I have time today, I'll probably do it at lunch. I think it's very, I think, this is one of my favorite units to teach, is the weather unit.

Sarah said that she would not really need to carefully look at the Teachers' Edition that offers the detailed guideline and suggestions. She mentioned that only novice teachers would need to read the teachers' guidebook. As a veteran teacher, Sarah seemed to find it less useful to follow the detailed guidelines that the Teacher's Edition provides, since she had a lot of resources to add to the existing text materials. In her teaching, Sarah actually brought in other resources, handouts, worksheets, and reading materials that BSCS textbook did not include. Most of the materials came from the middle school curriculum materials that she found useful to add to 5^{th} grade activities.

Thus, Sarah did not use the Teachers' Edition that was supposed to steer teachers' teaching toward the intended goals of the BSCS curriculum and clearly show the detailed instructional expectations for teachers (See Appendix C – Analysis of activities in the textbook). As a matter of fact, the Teachers' Edition specifies the detailed guidelines for teachers about how to lead classroom activities based on the 5E model, how to ask questions, and how to respond to students' ideas.

Therefore, given the fact that Sarah did not use the guides, recommendations, and advice suggested by the Teachers' Edition, Sarah's enactment of the BSCS textbook turned out to be not as thorough as Diane's in terms of following and meeting the BSCS's intended goals and rationales, making a salient contrast to Diane's ways of using the textbook curriculum. Whereas Diane not only used the activities and readings in the text, but also closely followed the detailed guidelines to implicitly or explicitly reach the intended goals for students' scientific understanding, Sarah exclusively chose the textbook activities and readings, making a less rigorous job to implement the intended goals and rationales of BSCS activities.

As suggested in the BSCS textbook, Sarah used three investigations: evaporation in the saucer pan, evaporation in four shallow dishes with different conditions, and condensation on an iced cup. Sarah set up the investigation activities as directed in the textbook. The students were also asked to carefully follow the directions of the textbook to complete the investigations. For instance, before conducting the condensation investigation with the iced cup, Sarah asked all of the students to read the textbook directions step by step. Sarah then asked students to read textbook questions related to the condensation activity. Sarah told students that they would come back to the questions to answer when they finished the investigation. However, it is interesting that Sarah did not make any time to think about the textbook questions afterwards.

After the class made an observation of the cold iced cup, Sarah had students start reading the textbook information about "Solid, Liquid, and Gas." During and after the students' reading of the text, Sarah put a great emphasis on the meaning and definition of scientific vocabulary. For instance, she asked the students to review the meaning of the terms they just read, such as freeze, melt, condense, and evaporate. Along with the textbook reading, Sarah provided the class with the additional worksheets for the students to work on the scientific vocabularies they learned. As they worked on the vocabularies in the textbook and worksheets, the students were often asked to use the dictionary to find the correct rhetorical meaning of the terms. Sarah and her students' ways to use the textbook are described with the detailed classroom occasions in the following sections.

Observing, Describing, and Explaining Observations

Before the class began the condensation investigation with the cold iced cup, Sarah asked all of the students to read the textbook directions step by step. She called on some of the students to read the two pages about the activity procedures about the investigation laid out in the textbook. The directions included: "Fill a dry glass or metal cup with ice and water," "Let the cup sit in the room for a while," "Record what happens to the outside of the cup," "Put the cup in a steamy bathroom after you've taken a bath or shower. Or, put the glass in the kitchen while someone is heating water on the stove. Then, make your observation." After students read each step of the directions, Sarah provided the class with her brief explanation and summary of each step, making sure that the students understood what to do next and how to do it.

Sarah showed an iced plastic cup to the class. She moved around the classroom with the cup, so that all of the students could see the cup. The students were then asked to observe the cup. The students immediately exclaimed, "It's wet" and "It's getting wet." They said that they noticed the water was getting wet around the iced cup. Interestingly, some of them included observations not directly related to condensation event, such as "It's shiny," and "It's not plastic." Since the cup was just set up with the ice, however, there was no noticeable change yet happening on the cup. It was too early to see the visible changes on the cup. Sarah pointed this out, saying, "When you put it out, nothing is going to happen immediately. We're going to watch it."

Sarah then asked students to make predictions of what would happen on the cup. Sarah copied down what students predicted on the board. She wrote three sentences: "Cup will expand," "The cup will become moist on the outside," and "The ice inside will melt."

After students' predictions, Sarah asked students to read textbook questions related to the condensation activity. The questions were: "Did your cup leak? Where did the water on the outside of the cup come from? What is the temperature on the outside of the cup compared to the temperature of the air in your kitchen? Where else have you seen water droplets on cold surfaces? Did you see water droplets on the plastic wrap in investigation 2? Does this investigation have anything to do with clouds? Explain what you think."

After reading the question, Sarah commented that they were going to skip thinking about the questions right now, because they did not do the condensation investigation yet.

> Sarah: **All right. Now, we're going to skip that because that's asking us about our investigations.** Let's look at "Ideas to Think About." We're just going to talk about these ideas to think about, and we're going to come back and see if we have the same ideas after we do the experiments. Vickie, read what it says for us.
>
> V: (Reading the direction) "Think about what is happening relative to the water. In your journal, explain what you think happened to the water. Describe the energy that was involved."

Sarah told the class that she would come back to see if all of them have the same ideas about the questions after the investigation. Thus students did not have to discuss or talk about the questions they read about condensation. However, it is noteworthy that the class did not actually come back to the questions even after completing the investigation. The students got the questions to work on, but they did not have any chance to really work on the questions until the class finished, making an important omission of the intended activity laid out by the textbook.

Instead, Sarah started focusing on finding the definition and meaning of scientific words. She pointed out one scientific term, "energy," from a question, "Describe the energy that was involved." Rather than helping students answer and think about the guided textbook questions, Sarah asked students to find the definition and meaning of the particular word, energy. Sarah asked them to look up the dictionary to find that out.

> Sarah: **"Describe the energy that was involved." There is a word that we didn't have for today. What is energy? Energy, when you talk about energy, the reason water is evaporated or it's changed shapes, what do you think happened to the water? Describe the energy that was there. Energy, what's energy?** Well, let's see ...
> Sarah: **Brian? You're sitting back there with a dictionary. Will you grab one and give us the definition of energy real quick? Um, I asked Brian, we're going to have him do it. Let's see, who thinks they know what energy is? Who said they know what energy was? ... Okay, William, nice and loud, give us the definition of energy.**
> B: (Looking up the dictionary and reading the definition) "Usable heat or electric power that makes physical work..."
> Sarah: Excuse me. **Read that again. Nice and loud.**
> B: (Repeating the definition from it) "Usable heat or electric power for doing physical work or lifting objects. Water, oil, the sun are sources of energy. The ability to act or do work or put forth a physical effort."
> Sarah: **In short, energy is the ability to do work, some kind of work!**

Based on the reading of the dictionary, Sarah made sure that students understood the definition of energy. Sarah repeated and explained how energy could be defined. Her explanation was based on Brian's reading of the dictionary, not based on her own ideas or attempts to unpack the literal meaning. In the following description of Sarah's class, the students were often asked to use the dictionary or textbook reading to find out the meaning and definitions of a variety of the scientific terms. After ensuring the class got the right definition of energy, Sarah got the class to move on to observe and describe the cold iced cup.

Students were then asked to observe outside of the iced plastic cup that was passed around from one student to the next. While passing around and looking at the iced cup, most of the students were touching, holding, rubbing, and wrapping the side of the cup with their hands. Actually there were not any water droplets or wet spots appearing on the cup. Some of the students looked at inside of the cup. While other students were waiting for their turns to look at the cup, Sarah told the students what observation she made, wrote it down on the board, and asked the students to copy it down in their journal.

Sarah: **I can tell you one observation I made. When I picked it up, there was a wet spot on the top of the desk. (Writing down: Obs-Wet spot on table)**
A: Do you want us to write this?
Sarah: Yes.
Students: Awww.... (Grumbling)

Even before most students finished their observations of the iced cup, Sarah provided them with the description of her personal observation on the board. While the students were looking at the cup, they opened their journals to copy down what Sarah wrote, "Obs-Wet spot on table." Sarah asked them to present what they saw on the cup. At the same time, Sarah asked some of them not to look at inside of the cup, nor smell the cup.

Sarah: Write your observations. ... Okay, what else do you notice as you guys are passing it?
Sarah: (Looking at some students smelling the cup and looking at inside of the cup) Ladies, all of you are missing the point. You're smelling it? The question was "what is happening on the outside of the cup."

Students: (But the students kept looking at the inside of the cup and smelling it)
Sara: Okay, what did you guys and girls observe? Vickie?
V: I observed that ... the same thing Travis said.
T: What did I say?
V: I observed that ... um ... it's kind of wet on the outside.
Sarah: Okay. **Tonya felt the moisture. (Writing down "Tiny drops of water on outside")** Okay.

These short and brief exchanges were all of the students' description of observing the cup that the class had. Since there were no volunteers to present their observations, Sarah called on one student, Vickie. Vickie looked a little embarrassed and finally said, "it's kind of wet on the outside." Then, Sarah wrote down "tiny drops of water on outside" on the board, which was not what Vickie said. And the students again copied down what Sarah got on the board. As a consequence, all of the students' journals showed the same writing and same description of their observation, since they all copied Sarah's notes rather than including their observation using their own words.

It is also noteworthy that Sarah did not give students many chances to say and describe things on the cup. Rather she asked them to look up the dictionary to find the definition of the term. But that was not substantive response to students' ideas. That was more of a procedural response that was not developed for further discussions around the students' ideas. Instead, the students were busy copying down what Sarah said and wrote.

While talking about what the class could observe on the cup with Sarah's lead, Sarah encountered a lot of classroom management problems. The students often did not finish what they were supposed to do, moved around the classroom, and made noises talking to each other. They did not often pay attention to what Sarah said. They did not follow Sarah's directions to observe outside of the cup. Many students kept looking inside of the cup and smelling the cup. They also did not stop talking even though Sarah asked them to do so.

Sarah: Josh, Josh, Josh?
J: What?
Sarah: I know that when we get pulled out like this it disrupts the whole thing, but, um, investigation three in your journal, you need to write. Calm down. Norman? (Students were busy talking to each other) Ryan! (More talking) Okay, now, some, put that in the trashcan right away, please. Now, everybody sit down.
Students: (Students still talking)
Sarah: **I want you to put your heads down on your desks for one minute to regroup and rethink. ... That wasn't it, it has nothing to do with your mouth. We're not talking.** You need to think about one minute to get back in focus about what we're doing, without any talking. Chelsea, stop talking. Now, I'm going to walk to the front of the classroom, no talking any more unless we raise our hands, because we don't have much time.

After making the class quiet, Sarah did not ask more students to present their observations of the iced cup. Instead, Sarah directed students to write down the particular sentence in their journal from the board she wrote.

Sarah: Okay. In your journal, under investigation three, **you should write that "little droplets of water formed on the outside of the cup."** (Showing the iced cup to the students) Do that. Then flip back to observation one, investigation one.
Students: (But most of the students did not write down and follow what Sarah asked them to do.)

But most of the students did not write down the sentence from the board, nor follow what Sarah asked them to do. The students looked not focused and Sarah was almost yelling at them.

Overall, with the iced cup investigation, Sarah began with a question, what is happening on the outside of the cup? Students observed the iced plastic cup, which did not make any water outside. However, after one or two students' very short presentation of their observations, Sarah directed them to copy down as she wrote the answer on the board. Thus, all of the students' journals had the same writings: "Wet spot on table" and "Tiny drops of water on the side". There was no exception, since they were just asked to copy Sarah's writing instead of their own observation and experience. Sarah as a teacher took a role to provide a correct answer based on her own views of factual description.

Throughout their observing of the cup, therefore, students did not have enough opportunity to really think about the question, what is happening on the outside of the cup? Even though the whole class read the textbook questions about condensation that could lead them to discuss more along with their observations, they did not think about the questions or ideas at all.

As a consequence, the students ended up lacking the opportunity to describe what is happening on the cup on their own words and build personal experience and observation through speculating about the iced cup example to relate to other examples to find pattern. Rather, what the students did from observing the cup was to simply copy Sarah's description of the iced cup, not build on their personal experiences and findings.

In the next day, Sarah began class admitting her mistake made in the last day. She figured out that the plastic cup would not work for making water on the outside. Sarah explained, "Because in the (textbook) directions it said to either use metal or glass." Sarah added, "The plastic was not a good conductor of heat," to explain why the plastic cup did not make water outside. She then showed the class the iced metal cup that formed water droplets running outside, but promptly put the cup away on the small table at the corner of the classroom, which most students could not see anymore. It was too short a time for the students to make observation of the cup.

> Sarah: Now, we pretty much knew what Mrs. King was expecting and what the science book was expecting, so we gave the answer that we

thought was right, but I did collect a can and I did make it melt, and as you can see, what's happening on the outside right now (showing the iced metal cup to the class). Lauren?

L: It's frosty.

Sarah: It's frosty looking. It's got little drops of water. Let's see what's going to happen. We already know what's going to happen. It's already started (putting the cup away to the corner).

Showing the iced metal cup, Sarah asked students a question of what is happening on the outside of the cup. One student, Lauren, described, "It's frosty." Instead of building on her description of the "frosty" iced cup, Sarah immediately told the class her own description; "It's got little drops of water." Sarah did not make a chance for the class to think about Lauren's "frosty" description.

The time was too short for students to observe the water formed on the metal cup, since Sarah put the metal cup away in a few seconds. Furthermore, it is particularly noteworthy that Sarah did not have other students communicate what they saw and observed on the metal cup except for one student, Lauren.

Again, the class did not have a chance to closely look at the iced cup to build experience and individual observation of condensation example, nor develop further discussion to enrich their descriptions to find pattern in those experiences. Although the class finally got the nice iced metal cup that they were able to clearly see the water forming outside, Sarah focused less on creating classroom opportunities for the students to bring in diverse personal experiences for finding scientific pattern. Instead, Sarah focused heavily on providing the students with only one definitive factual description, "it's got little drops of water," looking for one "right" and "correct" description or answer of the scientific phenomena.

Sarah then moved on to ask students to explain the example of condensation. Sarah began with the question, "What causes the condensation on the side of the can?"

> Sarah: Now, what happens when I put, and somebody is going to do this, if you look at that you can already see the water droplets forming, I need somebody to tell me "What causes the condensation on the side of the can?" Travis?
> T: The moisture on the inside is getting cold, so on the outside…
> Sarah: **Where is the heat being transferred from? Raise your hand. How is the heat transferred?** Vickie?
> V: Um…
> Sarah: **How is heat transferred? Zach**?
> Z: From warm to cold.
> Sarah: **From warm to cold! In this case, where is the warm?**
> Z: On the outside.
> Sarah: Our surrounding, where is the cold?
> Z: On the inside.
> Sarah: All right.

Given Travis's response, Sarah followed up with another question, "where is the heat being transferred from?" and "how is the heat transferred?" She turned students' attentions to "heat transfer" to explain condensation. The students said that heat is transferred from warm to cold. Here, whereas students' explanation of condensation based on the temperature condition of condensation, coldness causes condensation, Sarah's focus had already moved on to "heat transfer" to explain the phenomena of condensation.

Sarah did not seem interested in working on the key scientific pattern, the temperature condition, Travis brought up. This is another interesting contrast to Diane's teaching. Diane's main interest and focus was on elaborating and building on the key scientific pattern over and over again, instead of expanding to extensive scientific theories. But, here Sarah seemed to focus more on working on other theories such as heat transfer, as she had shown in the content interview. This feature of less focusing on the scientific pattern is described below. In the following section, ways in which Sarah provided her own scientific explanation to the students are described in detail.

So far, therefore, Sarah did not provide students with opportunities to build experiences to find patterns, which did not nurture students' practical reasoning – understanding condensation between experience and pattern back and forth. Given the limited opportunities to extend their experiences, students seemed to have lack of chances to relate their experiences to other experiences. Now, Sarah's ways to help students understand scientific explanation are described below.

Taking Teacher's Explanations

In the following exchanges between Sarah and students, Sarah asked many "how" and "why" questions to engage the students in explaining the example of condensation. In responding to students' ideas, Sarah began explaining how and why condensation happens to the students.

Sarah: Now, how does it get this moisture on the cup?
C: I know!
Sarah: What causes this moisture on the cup? Christian, how?
C: When the water evaporates, it leaves it behind.
Sarah: When the water evaporates, it leaves it behind. That's a good prediction and a good thought. Does this cup have a hole in it so the water gets to the outside?
Students: No!
Sarah: No? Well, there's one right there. (Pointing to the top of the cup)
C: …
Sarah: What? Dylan?
D: It doesn't matter.
Sarah: What doesn't matter?
D: That it has a hole in it.
Sarah: You mean at the top?
D: Yeah.
Sarah: Okay. **So why does it have moisture on the outside of it then? We just found out that heat goes from, uhh, the heat is transferred**

from warm to cold, and we decided that the warm was outside the cup, but how come I've got water on the cup? What's making water on the cup? Josh?

Josh: Because the heat, the heat and cold meets the heat and the cold, it makes the water drops.

Sarah: All right.

Sarah: **But where are the water drops coming from?**

Josh: In the air.

Sarah explained that the heat transfer is involved in making water drops on the cold cup. Despite her explanation of the heat transfer, Sarah did not seem satisfied to explain how condensation happens. Sarah then continued to ask another question, "But how come I've got water on the top?" To Sarah's persistent question, Josh responded with a cold-warm temperature conditions, saying, "Because the heat and cold meets, it makes the water drops." But Sarah still did not seem satisfied with Josh's temperature conditions, either, showing the difference between his focus and Sarah's. Sarah then followed with the next question, "Where are the water drops coming from?"

Followed by Josh's response, "in the air," the following dialogues went on.

Sarah: All right. So, we have air that you know, you can't see it, but air is like my hand, it's constantly touching you. All of you are walking through a field of air every time you walk around the room or move or whatever. You've got all the atmosphere. **So the air is coming close to the can. What happens to air when it's cool?** Zach?

Z: Air like, it turns into like another, you can see it…

Sarah: **What does it turn into?**

Z: Like a gas kind of?

Sarah: **It is a gas, but what is the gas turning into, Josh?**

J: A liquid.

Sarah: **All right, the gas is turning into a liquid, because why?**

M: Because it's getting, um…

Sarah: Travis?

T: Because cold makes the air turn back into water?

Sarah: All right, **the air is cooling, isn't it? We already learned that when a gas cools, it becomes a what?**

Students: Liquid!

Sarah: **A liquid, so what's happening here is first of all I've got my cold, cold water on the inside of the can, and I've got water that's**

pushing, I mean air that's pushing in against the can, and the can is what temperature now?

B: About zero.

Sarah: **Yeah, it's really cold, isn't it? So when that warm air hits that cold, cold can, what's going to happen to it? ... When the warm air hits the outside of the can, what's going to happen to that warm air?**

M: It...

Sarah: (asking student, M, to touch the metal cup) Touch the can, touch it...

M: It's cold.

Sarah: What else?

M: It's wet.

Sarah: **It's wet! So what happens to the gas? It gets what? It gets wet. It turns to a liquid, okay?**

Sarah asked a substance-tracing question. Sarah engaged students in thinking about the process of getting the water on the cup. She began with a question, "What does it turn into?" Again Travis explained with a coldness temperature condition, "Because cold makes the air turn back into water." But Sarah did not seem to consider this to be an adequate explanation and probed more with another question, "when a gas cools, it becomes a what?" Sarah was explicit at guiding students to use the particular vocabularies, such as gas and liquid, rather than Travis's vocabularies, such as the air and water. Sarah repeatedly put an emphasis on the fact that the gas is turning into a liquid, which is the theory of changes of state.

In particular, it seems that Sarah had some sort of concept of the change of state, but not of substance. She consistently emphasized that gases turn to liquids when they cool, but does not try to specify which gases and which liquid. Sarah seemed to be satisfied as using "air" as a rough synonym for "gas" and "water" as a rough synonym for "liquid."

This contrasts Diane's teaching practice. Diane did not use the scientific terms, such as gas and liquid, nor introduced the scientific idea of turning the gas into the liquid at all, which is the theory of the changes of state. Rather, Diane focused more on working around one scientific pattern, the cold object and the warm air make condensation, over and over again without referring to other scientific terms or theories. In contrast, Sarah used a lot of scientific vocabularies and theories to explain condensation to the class. She guided students to use the terms, gas and liquid, leading the class to think a lot about the theory of changes of state between gases and liquid, and the theory of heat transfer.

Thus, Sarah, like Diane, seemed to have a consistent message for the students, "Gas turns into liquid (or air into water) when it cools," showing that she implicitly addressed the key scientific pattern of the temperature condition. When she did this, though, Sarah seemed to implicitly introduce substances, but in an incomplete and confusing way.

Overall, Sarah's explanation was less successful in her teaching practice. She often used the vague scientific terms, such as the air and gas, but she never explained that they are the gaseous water or the air containing the water vapor. Like in the interview, Sarah did not make clear the meanings of the terms for herself or her students. For instance, Sarah explained how "the air" or "gas" turned into the water droplets on the outside of the cup, but she did not make clear whether "the liquid water" is the same substance as "the air" or "gas."

Thus, Sarah seemed to have a less clear idea about how the substances in water could be traced from the gaseous state to the liquid state. This feature of her knowledge that appeared in the classroom teaching is consistent with her scientific knowledge shown in the content interview. In the content interview, Sarah also lacked clarity about the process that leads to water form-up on the iced cup, often obscuring what she meant by many terms such as gas, air, vapor, oxygen and hydrogen.

Use of Textbook's Explanatory Reading

After Sarah's explanation was offered, the class started reading textbook information about "Solid, Liquid, and Gas." During and after reading of the text, Sarah put great emphasis on the meaning and definition of scientific terms. For instance, after reading a half page of text about three different states of matter in water, Sarah reviewed the meaning of "freeze" and "melt" with students.

> Sarah: All right, **we've got important words there. We've already had most of them. Freeze, what does the word "freeze" mean? Hands please. Freeze, what does freeze mean? If I freeze something, what will I do, Christian?**
> C: You turn the liquid into a solid.
> Sarah: You turn the liquid into a solid by doing what? I want to know what freezing is. Travis?
> T: (looking at the text) … Taking away the heat.
> Sarah: All right, freezing means you remove all the heat. What temperature does it have to be?
> Students: Zero!
> Sarah: Zero degrees what?
> Students: Celsius.
> Sarah: Okay. So we're going to remove all the heat and then it is a what?
> T: Solid.
> Sarah: **Solid! You need to remember it. What does the word "Melt" mean? If I melt something, what do I do? Jessica? If I melt solid ice, what do I do?**
> J: Add heat.
> Sarah: **I add heat, and then solid ice becomes what?**
> J: Liquid.
> Sarah: **Solid becomes a liquid, now we can do that with butter and chocolate and all kinds of things.**

With Sarah's questions for reviewing the meaning of the words, students had to look back at the textbook to find the definition of each word. Basically the students had a chance to review the content of the textbook for finding out the literal explanation of the terms. Sarah then wrote down the short definitions of "Freeze," "Melt," and "Condense" on the board.

Sarah: All right, the next word is "Condense." What does the word "condense" mean? Chris, what does the word condense mean? Water condensed on the side of this pan. What does condense mean? What does condense mean?
C: Melt.
Sarah: Well, no! Not melt. What is happening to the...
B: Freezing.
Sarah: No, it's not freezing. What is happening to the gas on the side of this can? Tonya.
T: A liquid.
Sarah: **It's becoming a liquid, all right. So, some of you say, but you don't always have your hands in the air. Some of you say answers all the time. All right, condense means that it's going to be made smaller, smaller, and smaller, okay? You've got the gas, and when we put the molecules together, it condenses. It comes together, okay? Condensation. Moisture are usually related, condensation we think of moisture, (writing down Moisture on the board) although we can get it with lots of other things, but for this one, it's condense.**

Here, Sarah explained condensation, using the literal meaning as well as the scientific term, molecules, at the microscopic level. First, Sarah introduced the literal meaning of "condense," by saying, "Condense means that it's going to be made smaller, smaller, and smaller." And then she continued to mention, "When we put the molecules together, it condenses. It comes together."

Sarah did not make a further explanation of what molecules mean, though. She mentioned molecules to explain the meaning of 'condense', but she did not make clear how "putting molecules together" can make the gas condense. Without the accurate explanation of the changes of state, her explanation of condensation was incomplete, and it was too hard for students to make sense of it. Thus this occasion echoes her explanations about the changes of state in the interview. In the interview, Sarah had not demonstrated an accurate explanation of how the gaseous state turned into the liquid state.

Sarah then associated condensation with "moisture." She wrote down "Condense – moisture, liquid to gas." Given Sarah's wrong note, "liquid to gas," one student immediately opened the dictionary to read the definition of condensation to the class, pointing out the wrong note.

> D: **In the dictionary, it says ... to change from a gas to a liquid form.**
> Sarah: That's what we just said. No, well, I did a tongue tangle, but she said the right thing. You change a liquid to a gas... and there's usually some kind, no, you're forming a liquid. I need your attention up here, Vickie, you too. Okay, and then evaporate, what does the word evaporate mean? What does the word evaporate mean? Christian?
> C: It turns into a gas.
> Sarah: All right, it's going to turn from a liquid to a gas.

It is noteworthy that the class seems to rely on the dictionary as a main resource to find the meanings of the important scientific terms. The class kept moving on to search for the definition of other words, such as evaporation and precipitation.

Overall, Sarah's use of textbook reading focused heavily on reviewing and finding out the definitions and meanings of the scientific vocabularies. Most of the time, students looked up the textbook reading along with the dictionary to find the correct definitions. Thus, Sarah spent the most time working on finding the definitions and meanings of the terms, instead of trying to make sense of the scientific phenomena and examples. Sarah's frequent emphasis on finding the definitions of scientific words also appeared in her assessment of students' learning as described in the following section.

Assessing Students' Understanding

During the lessons, Sarah assessed students' understanding several times. Sarah used the assessment items and worksheet materials copied from the middle school curriculum. Right after finishing the reading of the textbook, she passed out a review worksheet to the students. She put up an overhead slide of the worksheet and began asking some questions to the students. The questions were about what they read about the terms evaporation, condensation, and precipitation. The task for the students was to match three scientific terms to the given definition/explanation. The questions included: 1. The process in which a liquid transforms into a gas is called _____; 2. Snow, sleet, and rain are all forms of _____"; 3. What happens when a gas turns to a liquid? _____.

> Sarah: (Reading the question 3 on the slide) Okay, what happens when a gas, what happens when a gas turns to a liquid? What's that one called? What's it called? Zach? When gas turns to a liquid, what process is that?
> Z: Heat! I mean, ... umm... Water vapor!
> Students: Condensation!
> Other students: Precipitation! (Repeated amongst themselves)
> Sarah: **(Writing down the answer, "Condensation," on the slide) All right, know those words.**

Students had a chance to review the term, condensation, along with the definition of it. Sarah wrote down the right answers to each of the questions with a marker on the slide and asked students to copy the correct answers on their sheets.

At the end of the lesson, Sarah passed out another worksheet that included the blanks in the diagram of the water cycle. It also had the list of the questions, including:

In the illustration above, label the parts of the water cycle and draw arrows to show the movement of water; What are two factors that can cause water to evaporate more quickly?; What determines the form of precipitation that will fall at a certain time?; Explain the statement, "Last spring's rain, this winter's snow."; What are some sources of the water vapor in the air?; Much of the precipitation that falls on land surfaces eventually makes its way to ______.

The students were asked to fill in the blanks in the diagram. Sarah said, "Label it. Use your book." The students were allowed to look at the textbook and the words written on the board. So they just copied the three big labels, evaporation, condensation, and precipitations. Thus the students had another chance to review the three big terms in the water cycle, but they were not asked to consider any examples, key patterns, or the process of each stage in the water cycle.

> Sarah: Read what it says for us in number one.
> L: (Reading the question 1) "In the illustration above, label the parts of the water cycle and draw arrows to show the movement of water."
> Sarah: All right, **your first thing there is to using the words evaporation, condensation, and precipitation, label the water cycle. The words are on the board, condensation, evaporation, precipitation. Label them the way they should be labeled.** ... Label the water cycle. Okay, let's go on. I tell you what, you go ahead and finish this the best way you can, and see what you can come up with and we'll check them tomorrow.

Sarah then asked students to answer the rest of the questions on the worksheet. But, as shown above, some of the questions focused on ideas that had not been discussed in class. After reading the first question, she let the students work on all of the questions on their own. The rest of the questions were not read together with Sarah. Although the questions were not clear to understand, Sarah did not help the students better understand what the questions meant and complete the task. The majority of the students were not able to answer the questions. Most of the students left the classroom with a lot of columns left unanswered.

In the next day, Sarah passed out a half page size of blank sheet to each student. She then asked students to draw the water cycle on the sheet. She told the students the three big words, evaporation, condensation, and precipitation so that they could put the words on their paper.

> Sarah: This is about a five minute exercise. It shouldn't take you much more than five minutes to finish it. (Students talking) If you talk, it will go in the trash and you will receive a zero. I will give the directions once and only once.
>
> Sarah: **If you listened yesterday, you won't have any problem. On the sheet of paper, draw a picture of the water cycle, label these words, evaporation, condensation, precipitation, and draw it in. On the sheet of paper I gave you, draw the water cycle, label it using the words condensation, precipitation, and evaporation. Can we start?**
>
> Students: Yeah!
>
> Sarah: When you're finished, listen, bring me your paper and go get your science book.

After 5 minutes later, Sarah asked one student to come up to the board to draw and label the diagram for the class. Students had another chance to remember the three stages of the water cycle.

The interesting thing is that although Sarah spent lots of time having students conduct investigations, listen to her explanation of how condensation happens, read the textbook to learn about the scientific meaning of each terms, Sarah just gave them a review test of matching the three words to a diagram in the water cycle.

Later in the class, students worked on "Weather Cross Words Puzzle." The puzzle included a list of scientific terms and names of some instruments related to the weather and the water cycle. They included: Condensation, Precipitation, Evaporation, water vapor, water cycle, solid, liquid, gas, clouds, meteorology, barometer, thermometer, anemometer, psychometer, hygrometer, rain gauge, humidity, and cirrus.

Students were asked to find the weather words on the cross puzzle. After completing the puzzle, all of them were requested to look up the dictionary to find the correct meaning and definition of each word. From this assessment task, it seems that Sarah wanted to help students gain the accurate factual, rhetorical definitions of the scientific terms and vocabulary, by asking all of them to look up the words in the dictionary. This feature of Sarah's assessment, focusing on the definition of the words, appeared repeatedly, as described above. This feature was also shown in her administration of post-test after the lesson was all finished.

At the end of the unit, Sarah gave out the post-test to students. The questions in the post-test included:

1. Draw and label the water cycle. Use the words evaporation, condensation, and precipitation. After completing your drawing, explain the meaning of each word.
2. What is the energy source that drives our weather?
3. Describe or draw each of the cloud types: Stratus, cumulus, cirrus
4. Describe/draw the set up for the "smoke box" investigation. What happened when we did the investigation in class? What should have happened? What was the purpose of doing this investigation?
5. Name four things that affect the weather.

All of the post-test questions asked the students to come up with the literal definition and meaning of the scientific words, which looked more like a simple memorization test. It is particularly noteworthy that there was no question item about thinking about their personal experience and observation through the investigations, making a list of the examples of the scientific ideas, thinking about what pattern they could see, or explaining why and how three processes, e.g. condensation, of the water cycle happen. Instead, the students were asked to name the definition and meaning of the terms, draw the water cycle and explain the meaning of each word, and name the things that affect the weather. Thus, these questions were not designed to assess students' scientific reasoning and understanding of the scientific phenomena in condensation.

Later, Sarah graded the students' answers. Her grading focused on checking if the students included the correct answers. She used A, B, C, and D scales. Among total 23 students, for instance, most of them (19 students) got grades either D or E – they did not answer to most of the questions. Just 2 students got A. 1 student got B. 1 student got C. Though, all of the students included the three big words without any mistakes: Evaporation, condensation, and precipitation. But most students showed difficulty coming up with the correct meaning of the words and the accurate explanation of the terms. Thus, the post-test result shows that students mastered the literal names of scientific vocabularies, but without gaining the detailed meaning of the words. Based on what they answered, the students did not answer what the vocabularies, evaporation, condensation, and precipitation, meant.

Although Sarah frequently engaged the students in finding out the correct definition and meaning of them by looking them up in the dictionary and textbook, interestingly Sarah's approach did not seem to be conducive to forming opportunities for students' learning science through making connections among experiences, patterns, and explanation. The students could not even "remember" the definition of the words even after spending lots of time looking up the dictionary. This signals that without deeply reasoning about the scientific ideas around the words, it seems meaningless for the students to simply memorize or look for the definition of the words.

Overall, Sarah's assessment in both review tests and post-test focused mainly on evaluating students' knowledge of definitions and literal meaning of the scientific terms. This way of evaluating students' factual knowledge seems to be quite consistent with her other teaching practice, which focused heavily on teaching students to develop the accurate definition and meaning of the scientific language and vocabularies. Sarah exhibited less interest in including some assessment items to see whether her students achieved scientific understanding of the phenomena of condensation, since she did not evaluate students' ability to find a pattern in experiences and to develop a scientific explanation in any form of assessment.

Commentary on Sarah's Teaching Practice and Students' Learning Activities

In her classroom teaching practice, Sarah exhibited her scientific knowledge as working less on elaborating her explanation with experiences and patterns, but focusing more on using lots of scientific vocabularies that she did not clarify. Sarah spent less time having students make observation and develop their description of the scientific phenomena of condensation. Furthermore, although students came up with a key scientific pattern, the cold object and the warm air make condensation, Sarah, unlike Diane, did not seem satisfied with working with the key pattern. Instead, Sarah looked for other scientific words to explain the example. However, her explanation relied on the scientific words and turned out to be often incomplete and imprecise. She neither made clear the distinctions between the air, gas, or vapor from the water vapor, nor did she accurately explain how the water could be formed on the cup between the different states in her frequent use of the scientific terms.

So, the feature of her scientific knowledge in teaching practice appeared to be consistent with her scientific knowledge shown in the content interview. Sarah's understanding of the changes of state without substance tracing seemed to contribute not only to her incomplete understanding of condensation, but also to her incomplete explanation to students. In her explanation of condensation, therefore, Sarah often used vague scientific vocabularies, (e.g. gas, molecule, etc.) and theories (e.g. the changes of state) without making clear accounts of them.

In doing so, Sarah's teaching strategy, which was associated with her view of science, relied on using and looking up words in textbooks and dictionaries to teach students the scientific definitions. Sarah's view of science involved her belief that students learn science by mastering important facts and vocabulary. Sarah often asked students to look up the definitions of the scientific terms in the dictionary, write them down on the paper, and play games to reinforce the definitions of the words. During Sarah's explanation of condensation, the students were asked to copy down the accurate description and answers that Sarah wrote on the board.

In students' learning activities, students were engaged in mastering the definitions of the scientific terms, exhibiting procedural display. They did not have any opportunity to build experiences to find the key pattern, given the limited chance to make observation of the examples of condensation. Since the students were simply expected to listen to

Sarah's explanation based on a list of the scientific terms and then look up the meaning of the scientific words, they had limited opportunity to make personal sense of the material world through building experiences. The assessment results showed that even after spending time looking for the definitions in the dictionary, most of the students did not even remember the meaning of the words, since they were just engaged in less meaningful activity, which was to build the definitions of the scientific words, not to build experience to find scientific pattern. This hindered students' ability to make personal sense of the material world.

Reflection in Post-Observation Interview

In a post-observation interview, Sarah reflected on her teaching of condensation. She had a chance to think back on her original teaching plan. Sarah said that her goal was to teach students the different states of matter in the water cycle.

> Shinho: What were your general plans in your mind prior to your teaching of the water cycle?
>
> Sarah: Well I wanted them to know what, um, the phases of the water cycle were and how we got to those different phases of the water cycle. I think that was the whole point of the lesson, was to teach them the matter and the states of matter in the water cycle, they can identify what happened at each phase of the water cycle.

When Sarah was asked to think about whether she achieved the intended goals and plan, she said that her lesson went well since the students learned about the important phases of the water cycle, the states of matter, and a solid, a liquid, and a gas.

> Shinho: So do you think that you achieved your original plan?
>
> Sarah: I think pretty much but the kids know what a solid, a liquid, and a gas is and I think they know when they see rain it's a liquid, when they see ice it's a solid, when it's vapor it's a gas, so I think they link those two together and I think for the most part going back now and asking question to review most of them have got it and in fact they tell me when I ask what causes weather, those 4 words come in all the time,

precipitation, although that's not what I'm looking for, but that's carrying across, so I guess that was...

Sarah evaluated her teaching, saying that students knew well about the stages of matter at the end of it, including solid, liquid, and gas. However, when Sarah talked about the post-assessment, she was not satisfied with the result of the test. She said that although the assessment was not that difficult for the students, some students did not answer well on the test.

Shinho: How satisfied are you with this lesson?
Sarah: Well when I gave their assessment at the end I either didn't get all the points across like I should have or I had some ineffective listeners because from the results of the test and I didn't, I mean the assessment, I didn't' really think it was that difficult and some of them didn't have a clue what I was talking about, I mean you saw the... so somewhere along the line, either I'm not presenting it effectively or using the right technique in writing and listening and reading and feeling the whole gamut of learning then I need to go back and... if time permit it, and pull some of those kids out that I really lost and have them come in, but we're so scrunched for time it's not always possible to do that.

When she was asked to think about the reason why students showed difficulty answering the post-assessment questions, Sarah said that the students provided the causes.

Shinho: So, what do you think made them feel difficult in this lesson to learn the important content or ideas?
Sarah: **I just think it's a lack of attention and I think the transition from one class to the next, uh, really gets them, I don't know, excited or, just the change I think sometimes things happen in the hallway or they have to wait a little longer and by the time they come in here they're revved up and their mind is on anything but sitting for an hour and listening to science.**

Sarah attributed the students' unsuccessful learning to their lack of attention and motivation. Sarah seemed to think that her students did not work hard in science class, so the assessment in the water cycle ended up showing the low scores. Sarah's remarks reminded me that she often had classroom management problems. Sarah also seemed to think that because of students' lack of attention, she had difficulties keeping the science class focused on science content-specific learning and teaching.

Given a list of Sarah's scientific knowledge shown in the interview and teaching practice in her classroom, she was asked to talk about her perception about her own science content understanding.

> Shinho: How do you feel about your content understanding at this point in your career after finishing with the water cycle? Is there more that you need to learn about science content to be the kind of teacher that you want?
>
> Sarah: **I think I'm pretty knowledgeable, and like I say when I, when I'm in a store, especially at teacher's store, when I see something that's in one of the units that I'm teaching on, I always pull it out and look at it to see if there's more that I can add to make it more interesting. But I think I covered the content, I went through other different books to find things at work would keep the students' attention. I did the best that I could.**

When I asked Sarah whether there was more she needed to learn about science content, she did not say what particular topic or content she needed to learn more about. Sarah said that she was quite satisfied with her science content understanding, saying "I am pretty knowledgeable." She also seems to be satisfied with the fact that she is very enthusiastic at preparing her classroom activities with her purchase of many resources and materials for her teaching. Especially, Sarah mentioned, "I covered the content, I went through other different books to find things at work would keep the students' attention. I did the best that I could." Sarah seemed very pleased to "cover" the topic of condensation and bring in many other materials and resources into the classroom so that the students could focus on the tasks.

In particular, Sarah talked about views of science that turned out to be closely associated with her choice of teaching strategy for students to gain the accurate factual definitions of the scientific terms. In the following exchanges, Sarah showed her view of science that scientific knowledge emerges from authoritative sources, such as textbook, dictionary, etc.

In terms of students' working on finding the definitions using the dictionary, Sarah addressed ways in which the class engaged in the task. For instance, Sarah said that the class was given 15 words to put in their word search.

> Sarah: And listed them on the board and talked about them and then I said now "you choose 15 of these words to put in your word search" and then the intentions worked and then I did give them back to the kids, and they got to take them and work them with their print, so they really enjoyed. I think sometimes it's...
> Shinho: And then actually used a dictionary or...
> Sarah: Yes. **They had to know what the words were, if they didn't know what the word was they had to use the dictionary to look it up, and...**

Sarah mentioned that if students do not know what those words meant, they would need to look them up in the dictionary to find out the definition. When Sarah read the textbook with students, she focused on the meaning of the terms, such as energy, condense, vapor, air, etc. To Sarah, these were relevant words to learn the important ideas about condensation as well as the water cycle. So, she asked them to look in the dictionary to find the definition of each term and list them on the sheet of the paper.

However, there were many students who complained about finding the definitions and meaning of the scientific words in the dictionary. When she was asked to think about this, Sarah said that students liked word search of scientific words and vocabularies, but they did not like finding the meaning from the dictionary.

Shinho: Yeah, because this is interesting to me because from the conversation we had earlier, an hour ago, you said working on, they feel pretty good and focused on working on this kind of word search and I just noticed that they were actually loud.

Sarah: The reason that they were complaining was because they had to find the definitions of the words, **they were words that were introducing new words that we're using in the unit.** They didn't mind the word search, they thought that was cool but then I said when you're finished, you have to look these words up and use the dictionary, and they go, they don't like to do that. So that's why they were complaining and that's why I said oh no **because they have to do it anyway, you know, they have to know how to use a dictionary, use up that meaning.**

Although students were not happy with using the dictionary, Sarah seemed to think that the finding of the correct meaning of the words is an important aspect of learning. Besides using the dictionary, as she mentioned below, Sarah also engaged students in a game, so that the students could also learn for definitions scientific terms through the game.

Sarah: Like the tic-tac-toe, and then I ask a question like I might say the form of, um, water in, in liquid would be what? And they would tell me that it would be in liquid precipitation or whatever, you know, or define precipitation, or define the water cycle, and when they… they love the challenge against each other. Those are really successful activities and you know which kids, if you keep a little list or little charts, you know which kids fully grasp it, um, and then you have to, um, you have to repeat. You have to do it over because some of these kids just don't get it without…

Shinho: Repeat what?

Sarah: Whatever you're teaching. The four words, like **the four words from the water cycle and define it. You have to do a lot of going back over and retouching.** Not a lot, but, um, some things they're going to pick up very quickly and some things that they don't like, you're going to have to go over it more often.

Sarah mentioned that she wanted to have students define the important words from the water cycle. In doing so, Sarah had students repeat and go over several times, so they gained the definitions of the words, such as the form of water, liquid, or the water cycle.

Sarah's talk about emphasizing the importance of gaining the factual definitions of the words resonates with a consistent pattern in her teaching practice, getting students to find the definitions of the scientific terms in the book resources. Sarah demonstrated her view of science that the engagement of working on the definitions is more valuable to her than engaging in building experience to find a key scientific pattern. Instead, Sarah said that she emphasized helping students build the accurate meaning and repertoire of scientific vocabularies relevant to condensation. To help students learn the definition of the words, she developed specific teaching strategies, such as looking in the dictionary and playing word game. She was quite satisfied with her strategies and teaching practice to cover the content by keeping students' attention to the given tasks.

Conclusion

I argue that this was the case of an elementary teacher with a wide range of scientific knowledge and understanding, who ended up engaging students in procedural display without providing them with opportunities to make personal sense of the scientific world. Even though she demonstrated scientific knowledge with experiences and patterns in the interview, Sarah did not show the same type of scientific knowledge in her teaching practice.

In the interview, Sarah showed a similar level of understanding of scientific knowledge as Diane did. Like Diane, Sarah understood the key scientific patterns, the temperature conditions well. But, in contrast to Diane, Sarah rarely engaged in using the key pattern to make sense of condensation. Instead, Sarah listed a variety of scientific vocabularies to tell a story about condensation when she explained the examples of condensation and responded to students' ideas. She exhibited vague and unclear understanding of the terms she used, such as the molecules, vapor, and air. She often used the theory of the changes of state without an understanding of substance tracing.

In her teaching practice, Sarah employed a teaching strategy to help students increase a variety of scientific languages, echoing her view of science. Her view of science included the belief that gaining authoritative facts and definitions is the important aspect of doing science. Sarah believed that students learn science by mastering facts and definitions. Thus, Sarah focused less on relating examples to other examples to find the key scientific pattern, by providing less opportunity for the students to build their personal observation and experience. She did not center on helping the students find and understand the key scientific pattern, either. Instead, Sarah kept adding the vague scientific terms and descriptions of the changes of state and heat energy transfer without substance tracing, listing an array of scientific terms to construct a story about condensation.

In students' classroom activities, Sarah engaged students heavily in mechanically gaining the factual definitions of the scientific terms and vocabularies. The students were often asked to look up the definitions in the dictionary and the textbook reading. But the students' engagement in procedural display ended up not helping them engage in activities for attaining scientific understanding. However, the post-assessment designed for checking students' factual knowledge showed that even if they looked up the definitions in the dictionary, most of them had difficulty remembering the meaning of the words. In Sarah's class, thus, the students did not get any opportunities to learn science to make sense of the scientific world.

Whereas Diane's teaching practice, which worked deeply around making connections between the examples and finding the key scientific pattern, turned out to be effective at offering students opportunities to make personal sense of the scientific ideas, Sarah's teaching practice turned out to limit students' opportunities to gain scientific understanding through connecting various scientific knowledge. Thus, the case of Sarah exhibits that displaying a wide range of scientific terms is conducive neither to encouraging students' personal sense making nor to teaching for scientific understanding.

Thus, both Diane and Sarah's cases shed light on what types of scientific knowledge elementary teachers need for creating opportunities for students' learning. The important aspect of teacher's scientific knowledge and practice is the ability to relate and elaborate the experiences to find the key scientific pattern for constructing scientific explanation, and to make connection among examples, pattern, and scientific explanation. So, it is noteworthy that these two cases illuminate that teachers' scientific knowledge and practice plays a role to shape teachers' teaching practice in ways that can develop valuable opportunities for students to learn science and make sense of the scientific world.

The last case, the case of Kate, illustrates how a teacher with deep scientific knowledge and understanding engaged students in scientific reasoning, not only through evidence-based argument for which she carefully supported the students building the specific data and examples, but also through model-based reasoning.

Chapter Five

The Case of Kate

Overview

The case of Kate shows how a teacher made use of her scientific knowledge and conceptual understanding to make sense of the scientific phenomenon of condensation. Kate exhibited making intimate connections among examples, patterns, and scientific explanation back and forth in both her interview and teaching practice – in contrast to the other two teachers' limited scientific knowledge and understanding – as well as managing teaching strategy effectively.

Thus, this case demonstrates how an elementary teacher with good scientific knowledge and model based reasoning successfully nurtured classroom learning opportunities in order to engage students in developing scientific reasoning and understanding through making connections among examples, patterns, and scientific explanation, and managing evidence-based arguments effectively.

Kate

Scientific Knowledge and Practice as Shown in the Content Interview

In the interview, like the other two teachers, Kate was expected to meet three major expectations and roles as a classroom teacher, while talking about her ideas about condensation. They are (a) explaining the examples, (b) relating one example to other examples, and (c) responding to students' ideas or work. I tell a story of Kate to describe her scientific knowledge and practice, which are shown in her response to these three expectations. To highlight the features of Kate's explaining condensation, the portions of her responses that involve her main ideas are presented in bold.

Explaining the Examples

Kate was asked to describe what happens to the ice inside of the cup. She said that the ice would eventually melt by gaining heat from the water, since the water is warmer than the ice.

> Shinho: My first question is what do you think will happen to the ice inside the cup and why?
> Kate: **The ice is going to gain heat from the water that it's sitting in because the water is a liquid so therefore it has got to be warmer than the ice cube, so as it gains heat from the water, it will eventually melt and turn into a liquid and join the water.**

Kate related the ice melting to the scientific idea of heat transfer. Kate said that gaining heat would involve turning the ice into the liquid form of water. She explained the ice melting based on the theory of heat transfer and the changes of state between the ice and the water.

With a question of comparing the weight of the water from the ice melting with the weight of the ice, Kate made a prediction of what would happen to the weight in the iced cup. When Kate explained that the volume of ice tends to expand, she used her personal experience freezing a bottle of water.

> Shinho: How do you think the weight of the water from the ice melting will compare with the weight of the ice and why?
> Kate: Umm... **the weight of the ice cube and the weight of the water that it's going to change into has to be the same because I have the same amount of matter. But the volume and size can be different, because ice expands.**
> Shinho: Expands... what do you mean by "expands"?

Kate: It becomes larger. If you put ice into a bottle and freeze it, it becomes larger and pushes out, so ice tends to be bigger and when it melts I'm going to have a smaller amount of space taken up.

Kate understood that as the ice expands, the volume and size would change between water and the ice, but the weight does not change. This exchange demonstrates that Kate had a good conceptual understanding and scientific knowledge of both conservation of mass and the changes of state. To explain the example of changing matter, Kate not only employed scientific explanations, but also brought in her personal experience, demonstrating how she could make connections between her personal experience/examples and scientific explanations/theory.

The below exchange confirms her good understanding of the theory of conservation of mass, relating to the example of a balance of the iced cup.

Shinho: What would happen to a balance of the iced cup as time passes by, like this diagram shows?
Kate: **It should remain the same, because matter isn't going to be changed. It's not going to go anywhere, it's just going to change states.**

Kate said that a scale of the iced cup would not change. Kate seemed to have a clear idea of how to relate one theory, conservation of mass, to the other, the changes of state in order to make accurate sense of the example of the ice melting.

With a question of what would happen to the outside of an iced cup, Kate exhibited how she was able to adequately use the various types of scientific knowledge to make sense of the examples of condensation.

Shinho: What would happen to the outside of an iced cup?
Kate: Okay. Umm… **depending on the weather or where it is, it's going to gain condensation or liquid water on the outside of the glass and will also leave a ring on the table or wherever it might be sitting as the condensation runs down, and the amount of condensation will**

depend on the amount of moisture in the air and probably the temperature on how quickly it may change.

Shinho: Why do you think that happens? The moisture on the outside of the cup.

Kate: **There is moisture in the air all around us and around this cup, and as this cup of ice sits here it is colder than the air surrounding it so the air is going to lose heat to the glass of ice water and the moisture that is in the air around the cup will lose enough heat to change from a water vapor, gas state, into a liquid state and go on the cup.**

Kate said that depending on certain conditions and factors, condensation would take place. Kate used her everyday observation, a water ring left on the table in this case, to make sense of condensation. She then showed what pattern she found from the example of condensation, by specifying the multiple conditions involved in forming the liquid water on the outside of the iced cup. She articulated this in terms of three factors: the humidity factor from the amount of moisture in the air, the temperature factor, the cold object and warm air condition, affecting the speed of condensation, and the amount of heat changing the states between water vapor and liquid water. In explicating the influence of these factors on condensation, Kate demonstrated that she made scientific sense of how condensation happened through making intimate connections among her personal experience, scientific patterns, and scientific explanation, which were based on her detailed and skillful use of the ideas and terms, that the other two teachers, Diane and Sarah, did not show.

When Kate was asked to explain where the moisture on the cup came from, she provided a detailed description of how matter is transformed from one state to the other.

Shinho: Where do you think the moisture on the outside of the cup came from? Was it something else before it was liquid water, or what?

Kate: Okay, **the water from the outside of the glass came from the water vapor that was in the air surrounding it. It was a gas, and it has changed into a liquid and there were smaller molecules of water**

when it was in the gaseous form that as it cooled joined together and became more molecules in visible form of a liquid.

Kate said that the water vapor in gaseous form turns into water as a visible form of a liquid. She traced the matter of water between the air and the cup. In doing so, Kate seemed to engage in reasoning through "substance tracing" along with her detailed description of changing the states. She was able to clearly articulate how she understood the theory of the changes of state and substance tracing. In her explanation of condensation, Kate used the term, "smaller molecules" and "more molecules."

To clarify what she meant by the idea of molecules, the following exchange occurred. My question began with asking her why she chose the term, "molecule," to describe condensation.

Shinho: So you are using a word, molecule. Why are you using the word, molecule, rather than water vapor? Is that different idea? Between water vapor and molecule, is there a special reason you use the molecule?

Kate: I don't know why I guess I used it, but I see water vapor, if I could grab a handful of water vapor, the number of water... **individual water molecules probably would not be as many as if I could take a cupful of liquid, I'm thinking they're more compact, there's more of them together. So I would have more molecules,** and I guess I'm not 100 percent sure of what I'm saying is 100 percent correct cause I haven't had any of this molecular type stuff in quite a while and I don't really teach that so... I'm thinking that's...

Kate compared the gas molecule to liquid molecule. Although Kate was not so sure if her understanding of the molecule was correct, she demonstrated that she understood the changes of state at the microscopic level. She was able to explain how the different states among liquid and gas have different molecular compactness. Kate continued to talk about how she could use the term "molecule" to explain condensation.

Shinho: I'm wondering how we can actually apply the notion of the molecule to the outside of the cup, like condensation.

Kate: Okay... **I guess when I think about it, it's the number of molecules of water on the outside of the cup, there's more of them because we've got a lot more joining so that it's visible when the molecules are in the air. There's not as many individual molecules stuck together, which is why we can't see a gas, because they're so spread out and so far apart.**

Shinho: So are you saying that there are more molecules on the outside of the cup than the gas in the air?

Kate: Well, probably not, if I took all the air in this room and compared it to the molecules on the cup. No, there's probably more in the room.

Shinho: In the room?

Kate: I guess I'm just looking at the actual water molecules of the air that might be touching that cup. ... Just the... portion touching the cup but not in the whole... air ... in the whole room.

Kate said that the different states of matter have different molecular arrangements. She mentioned that the reason why we can't see gas in the air is because there are fewer numbers of gas molecules as opposed to the liquid molecules on the outside of the cup. Whereas, as she said, we are able to see the water on the outside of the cup because there is a lot more joining and being stuck together.

Overall, in her explanation of the examples of condensation, Kate engaged in using scientific explanations and theories to make sense of the phenomenon of water forming on the iced cup. Kate made use of the multiple theories of conservation of mass, heat energy transfer, changes of state, substance tracing, and molecular theory. She exhibited a good conceptual understanding of these theories. Besides using scientific theories, moreover, Kate often related other examples to the iced cup example, and used patterns in the examples to explain condensation. Further, Kate showed how she made intimate connections among examples, patterns, and explanations to make sense of condensation. Compared to the scientific knowledge and understanding Kate demonstrated, the other two teachers, Diane and Sarah, did not show this feature of scientific knowledge. Diane did not rely on scientific theories to explain condensation.

Sarah's understanding of the theories turned out to be not as complete and accurate as Kate's in spite of her frequent use of the scientific terms. Below, Kate's ability to connect various examples to find patterns is described.

Relating One Example to Other Examples

Kate was able to list various examples of condensation. By relating the various examples to one another, Kate demonstrated how she came up with the pattern in the examples.

> Shinho: Can you think of other times when something like this happens?
> Kate: I think about **when you take a shower and your mirrors steam all up, so the water's hotter than the air in the room so it fogs up your windows. Fog outside, when the ground is a little bit warmer as the air goes up and cools it changes into a light fog.**

Kate related the example of a foggy mirror in a shower to fog outside on the ground and then stated the temperature condition of condensation, comparing the temperature of the water to the air, as a key scientific pattern of condensation. Kate then added more examples of condensation: the car window on the inside and breathing on the window.

> Shinho: Any other examples you can think of?
> Kate: Umm… **your car. I know when we go and work out or have gone swimming at the Y and we all get in the car and we're warm, the windows on the inside will fog up, or when you breathe, breathe on the window, you can sometimes get some condensation.**

Responding to students' ideas or work

In the interview, Kate exhibited how she would respond to students' various ideas or work. She showed three features of teacher responses to students' ideas: (1) her evaluation (more content-centered), (2) her description of students' thinking (more student-centered), and (3) her response with justification (socially oriented). With the five students' ideas, my initial expectation was for her to follow through the order, that is, starting with her content centered evaluation, then moving on to the other ways of responding, concerning a student-centered and socially oriented classroom environment.

However, in her responses, Kate immediately started off with her description of what students are thinking rather than responding with her content relevant evaluation or social response to their ideas. After her description of students' ideas, then Kate provided her critical evaluation of the ideas based on her content understanding and made correction of the incorrect ideas. However, Kate did not seem to be concerned about giving a socially oriented response to justify various students' ideas by considering most of them as acceptable ideas, unlike Diane's and Sarah's primary ways to respond students' ideas.

With Jane's idea, the iced cup is sweating, Kate contrasted the students' idea of sweating in human's body to the water appearing on the cold cup.

> Shinho: Here is a scenario. Let's spend some time considering some of your students' ideas about these classroom events? How would you respond to these students' ideas and what would you tell them about their ideas? First student, Jane, is saying that the iced cup is sweating.
>
> Kate: My guess is she's thinking that when she gets warm, she sweats, and water runs down her face, and off her arms, so she's thinking that she's relating the glass to herself and so the glass is sweating. Umm… I would probably then go to ask Jane. Well, **when she sweats, where is that water coming from, which it's coming from her body. So if the glass is sweating, then the water would have to be coming from the glass**. Okay, **so it's coming from inside the cup and going through the glass and coming on the outside**. And with that I know that's what a lot of, I'm thinking that's what a lot of kids are going to think because they're just connecting it to what they already know and just what little bit of life they already have, so I'm hoping to do an experiment that will help them realize that's not what's happening.

Kate described the students' common ideas that a lot of kids tend to think the glass is sweating like our bodies. Kate disagreed with the idea that the glass is "sweating," by saying that she would ask Jane more about what made her think that. Kate described that students often think the water on the cup is coming from inside the cup as the sweat in the body, evaluating Jane's idea of sweating as imprecise one. To help the students realize "That's not what's happening," Kate said that she would set up an experiment to controvert their incorrect ideas that the glass is sweating. In particular, it is noteworthy that making a counter to students' ideas with another experiments or activities was Kate's central teaching strategy to help students realize that their ideas were incorrect. Kate's ways of responding to students' imprecise ideas are described in the section of her teaching practice in the detailed episodes.

Kate was then asked to respond to the idea of the water coming from inside of the cup.

> Shinho: Second student, Paul, is saying the water outside of the cup comes from inside of the cup.
>
> Kate: Okay. He is, I think, in the same type of idea of Jane that it is coming through, I have done something like this with another group of kids in another school and that's the most common, logical thing **because they can't see water vapor out here in the air, the only water they can see is in that cup so the water's got to come from the cup, where else could it come from?** And… again having touched on evaporation, hopefully we'll get them thinking that it's coming back from the other direction.

Kate made another instructional suggestion to teach this idea better. She mentioned that due to the invisible nature of water vapor, students would have hard time understanding that the water is not coming from inside of the cup. With the topic of evaporation prior to condensation, Kate said, the students would be able to reason about the scientific idea. Thus, it seems that Kate was concerned about how to help students understand the process of getting the water on the side of the iced cup, as trying to engage them in substance tracing reasoning.

With Carl's idea of the water moving to the outside of the cup from the air, Kate said that Carl has a better idea than Paul and Jane did.

> Shinho: Carl is saying that the water in the air moves to the outside of the iced cup.
> Kate: Okay, so… I'm going to assume he is a little bit farther along in making sense of evaporation, thinking that if we've already learned that the evaporation, the water has gone into the air, then he's thinking well if it's the opposite, then it has got to be coming out. And so he's kind of a step ahead of Paul and Jane.

Kate seemed to reason that condensation is an opposite process to evaporation. She mentioned that since the water evaporates into the air, it also has got to take the opposite direction to re-form the water back.

With Mary's idea, that hydrogen and oxygen in the air are water on the cup, Kate explained why students often believe that hydrogen and oxygen are on the iced cup.

> Shinho: Mary is saying that hydrogen and oxygen in the air are water on the cup.
> Kate: Okay, so **Mary has seen or heard somewhere that water is called H2O and so she's assuming since water is H2O, then we've got hydrogen and oxygen on the outside of the cup**. She could be… a higher level student where **they've already talked about some of the molecular stuff, knowing that water is made up of that so she's telling me that there are hydrogen and oxygen atoms on the outside of the cup which makes up oxygen, err, water.**
> Kate: I probably would help her to see that "Yes, that's what it is."

Kate said that students with advanced level of ideas might think "hydrogen and oxygen atoms" make water on the cup. Kate mentioned that Mary's idea is correct, saying, "Yes. That's what it is." It seems that Kate was not clear whether the water on the cup is the same water in the air. She seems to think that hydrogen and oxygen need to make up the water on the cup instead of changing states, which contradicts what she explained about the examples of condensation based on substance tracing and the changes of state.

In the next exchange, Kate made a comment that she would not teach atoms or molecules to students in the fifth grade.

> Kate: But as far as at my grade level, at 5th grade, I'm not going to be teaching all of the atoms and molecular stuff.
> Shinho: Because?
> Kate: Because… at 5th, our goal is to introduce it to them, get them thinking about it, it's getting a little abstract. So a lot of our students won't be able to take all of that in, and they're going to get the molecular level and hit the water cycle again in the middle school in the 6th and 8th, 6th or 7th, or 6th or 8th. So… I won't ignore that student, but I won't make a whole lesson on it expecting all of my students to get it knowing that it's going to come at a little bit more of a maturity level that hopefully then they'll understand it a little better.
> Shinho: Do you think that it would be difficult for them to understand the idea of a molecule and atom?
> Kate: It is… umm… it is. Sometime I struggle with that a little bit because we don't teach any of the molecular stuff and we don't really teach atoms and molecules and all of this at the elementary. I do try to throw it in a little bit in my teaching just to kind of get them thinking because some kids are a little more advanced and they need it, so I have hit up, you know, everything's made up of matter and matter's made up of all these little molecules and they all stick and join together, so I touch on it to help those that kind of water and it may just help others make sense of it a little bit, but I don't focus on all my students have to know that and I'm going to test them on that.

Kate was concerned about whether teaching abstract molecular ideas to the students would be fine. Kate said that teaching molecules would not be developmentally appropriate for the elementary students. For some students who have an advanced idea that requires understanding of molecular ideas, Kate said, she would help them touch on the ideas a little bit. But she did not want to address such abstract ideas to all of the students as a whole class.

This shows that given a lot of abstract scientific ideas, Kate was serious about how she could consider introducing the appropriate terms and ideas rather than trying to give the students all of the ideas without careful consideration of their age level. This distinguishes Kate's scientific and instructional idea from Sarah's. Sarah used a lot of the vague terms and language of which she did not make clear sense. She did not seem to carefully consider ways to better fit the ideas and terms to her students. In contrast, Kate demonstrated conscientious thinking to make a better choice of terms, which would ultimately help students' understanding. This feature of Kate's considering the students' side is described in her teaching practice in the next section.

To Joe's idea, that water is evaporating in the cup and condensing on the cup, Kate responded that Joe understands well what happens on the cup. But also she made sure that condensation on the cup would take place at a different time from evaporation in the cup.

> Shinho: Joe is thinking that water is evaporating from the water in the cup and condensing on the outside of the cup.
>
> Kate: I would probably tell him that he's thinking that both things are going on simultaneously.
>
> Shinho: Okay. And then?
>
> Kate: That if water is sitting there, he knows that it can evaporate so there's the possibility that some of the water is evaporating off of the cup, and... he is understanding that we also have condensation going on the outside of the cup. If he thinks it goes from here and just immediately goes to here, I probably would try to make it clear that if there is a little bit of evaporating going on, in that real short amount of time, there's probably not much that's going to happen, so most of what's coming is stuff that has already evaporated at another point and now is condensing.

Again, Kate made a response with her description of how Joe possibly got the idea of the water evaporating simultaneously with condensing on the cup. She described how his thinking could be developed along with her evaluation about his ideas. Although

Kate thought that Joe was right in his idea of evaporating and condensing, she also pointed out that the two processes would not happen in a short amount of time. Kate emphasized that the water making condensation is not necessarily the same as the water in the cup.

Commentary on Kate's Scientific Knowledge and Practice in the Interview

In the interview, Kate demonstrated how she made intimate connections among experiences, patterns, and scientific explanations, back and forth, to make sense of condensation. She had good scientific knowledge of finding a key scientific pattern in examples of condensation and engaging in scientific inquiry. She also showed that she made sense of the phenomenon of water forming on the iced cup using scientific explanations and theories, engaging in scientific application.

Kate's scientific understanding was based on model-based reasoning. She was successful at explaining the examples of condensation and responded to students' ideas, using scientific theories and explanations. Her scientific reasoning was based on substance tracing, changes of state, and conservation of mass and heat energy.

In her responses to the five students' ideas, Kate also exhibited a useful and adequate understanding of the process of condensation. Her differentiation between sweating and condensation was clear and specific based on her idea of substance tracing. Kate's reasoning about how the water gets on the cup was also consistent with her sound explanation of the examples of condensation, as described in above section. Kate rarely responded to students' ideas in a way of ensuring socially comfortable environments. Instead of justifying how those naïve ideas are valuable for her teaching, she went straight to make a detailed description of the students' thinking and ideas, and then provided her content-centered evaluation on the students' ideas.

This contrasts to Diane's and Sarah's ways of responding to students' ideas. The other two teachers tended to focus more on making sure of nurturing a safe classroom environment by justifying and allowing students' diverse ideas and answers. In contrast, however, Kate's responses focused more directly on describing and evaluating the students' ideas with a content specific focus. And more importantly, she often made instructional suggestions either to counter students' incorrect ideas with other experiments and activities, and redesign the instructional sequences of the different topics, or to carefully consider the students' developmental level to introduce abstract ideas. This feature of her scientific knowledge and practice is consistently shown in her teaching practice in the following section.

Teaching Practice and Students' Learning Activities

Kate devoted a total of two class periods to teach condensation quite intensely. Compared to the other two teachers, Kate did not teach other scientific ideas, such as evaporation, precipitation, and the water cycle, along with condensation. Diane and Sarah broke up their class instructional time into several chunks to teach the different ideas within a given class time period. But Kate did not try to teach all of the different ideas together at once. Instead, Kate taught each topic one at a time.

Therefore, after she spent two class lessons on evaporation, Kate then moved on to having students work only on condensation. The students' learning activities focused exclusively on the topic, condensation, instead of trying to cover many of other different ideas. To teach condensation, Kate particularly developed and modified one investigation from the textbook, making the least use of the textbook materials among all three teachers. The relationship between Kate's teaching practice and her use of the textbook materials is first described below.

Kate's Teaching and Textbook Material

Kate exhibited actively modifying and making changes to the intended content, activities and investigation suggested in the BSCS textbook, compared to the other two teachers. Whereas Diane and Sarah closely followed the textbook materials in one way or another, Kate's ways of using the textbook stood out. Her modifications of the textbook activities were heavily based on her evaluation of the activity with her instructional decisions considering how to best enhance the students' scientific understanding. Kate made several changes in the classroom investigations of evaporation and condensation.

For instance, over two lesson periods on the topic of condensation, Kate set up one condensation investigation activity that was not exactly taken from the textbook. She came up with a modified activity, by adding two food colorings, blue and red, to the iced cups. Whereas Diane and Sarah used and followed the same investigation in the textbook without making any change or modification, Kate did not use the same investigation. Instead, she modified the iced cup activity with the intention of helping students overcome one of their common misconceptions about condensation. Since Kate did not actually follow the same activity in the textbook, Kate and her students did not have to look in the textbook to read directions or guidelines for the intended activity.

Therefore, Kate's teaching was primarily based on the colored iced cup investigation that she modified from the textbook. Her rationale was to provide the students with evidence that the water on the outside of the cup does not come directly from the water inside of the cup, since she thought that the students would be able to see that there is no colored water appearing on outside. She provided students with lots of chances to observe the outside of the cup and develop interesting classroom discussion and evidence-based arguments, rather than just following the textbook guidelines, questions, activities and reading information offered by the textbook.

Another interesting practice Kate showed was that she did not use any of the informational explanatory reading in the textbook in her teaching. The reading included scientific explanation about the different states of the water cycle, such as solid, liquid, and gas, the scientific meaning and definitions about evaporation, condensation, freezing, and melting, and the formation and names of clouds. This makes another contrast to other two teachers' use of the textbook, which was to read and use the textbook readings thoroughly. In the later interview, Kate said that reading the text is not conducive to students' scientific understanding. Rather, she said, textbook reading tends to reinforce their factual knowledge and meaningless memorization.

Instead, saying, "I really think that most of their questions are really good," Kate made careful and thorough use of questions to elicit students' ideas and help them think about their observations to find patterns. Kate's use of textbook questions also contrasts with the other two teachers' way of using them. In Diane's class, Diane used questions to ask students to answer them in the journals while making their observations. But without Diane's support students showed that many of them often missed the questions and did not complete their answers to the questions. In Sarah's class, Sarah read the questions at the beginning of the lesson, but never came back to discuss the questions again. So Sarah's students did not have a chance to think about the questions based on their observations and learning later on.

Compared to the other two teachers, therefore, Kate used the textbook questions to check if the students were able to answer those questions after finishing condensation investigations and discussions. Kate carefully asked each question to students and then probed with the follow up questions so that the students had more chances to think about the examples and patterns in condensation, and explain condensation based on their understanding. Kate's ways of using the textbook questions are described in the episodes of students' classroom learning in the following section in detail.

<u>Observing, Describing, and Explaining Observations</u>

Kate began the class with the modified investigation, which was to observe the colored iced cup instead of the iced cup. She had students observe the colored iced cup and asked them to describe what happened on the cup.

> Kate: (Putting the colored blue or red cups on each table) **I need you to take a quick look at these cups, and I need you to tell me what you see right now. What do you see,** Keisha?
> Ke: Not a lot.
> Kate: Charles… you've got to see something.
> C: I see solid ice.
> Kate: Where is the solid ice?
> C: Inside the cup.
> Kate: It's inside the cup. **What else do you notice?** Angelo?
> A: It's red.
> Kate: Are they all red?
> S: No.
> Kate: Some are blue. **What else do you notice?** Tammy?

Tammy: If you had like a lemonade cup on a hot day or something, you'll get water on the outside of it, and it's like that.
Kate: Okay, do any of these have water on the outside of them? How many can … can anybody see water on the outside of them?
Students: (Many students raising their hands) Yeah~~.
Kate: Okay, now, I carried these in here, right? You guys saw me carry these in right at 8:30 when you guys were coming in, right? Some of you were already in, some of you were coming in, and I just sat them over there, right? Please set them down. Set them down guys. **Did I pour water on the outside of them?**
S: No.
Kate: **Could I have spilled water on the outside of them?**
S: No, they were frozen. You couldn't have.

While students observed the colored iced cups, Kate asked students if they noticed anything on the outside of the cups. With the students saying that the water was on the outside of the cups, Kate seemed to want the students to begin thinking about "how" the water could get on the outside.

Before moving on to next activity, Kate asked students to wipe the water off outside of the cup to make all of the cups completely dry.

Kate: It was frozen. **What I would like you to do is I put a couple of Kleenexes on your table, and I use those because they were white. What I would like you to do is take your cup and Kleenex and I want you to kind of dry it all off.** The sides of the cup, okay, and you already know there was water on them when you got them. Just quickly, we should be done, just wipe them off and set them down on your table in the middle and then please don't touch them again until I ask you to. All right?
X: On the table?
Kate: How did your table get all wet?
X: The water got it wet.
Kate: Oh, so your tables are wet too already? All right, go ahead, set them in a dry spot then. **I would like the glass of ice sitting on the middle of the table, not on the Kleenexes, just go ahead and set them on the side.**
Kate: Charles, okay, leave it there now, and we're going to let it sit there for the next ten minutes or so until we come back. Now, Tammy's already made kind of a prediction. My next question was what do you think is going to happen, okay? Tammy told she knows it because of

her lemonade glass with ice. Xanthus, I asked you to leave them alone please.

Kate made sure that the students did not touch the cup again while the droplets were forming on the cup. By having students double-check that no water was initially on the dried cup, Kate seemed to want students to have the opportunity to observe water forming on the outside of the cup. In particular, Kate seemed to prepare evidence to show the students that the colored iced cup was somehow making water on the outside without somebody's pouring water on it. Later, Kate used this investigation to lead the whole class discussion of whether the water comes straight from the inside of the cup, by checking the evidence of the color of the water on the Kleenex.

Kate then asked students to make a prediction of what is going to happen to outside of the cup.

Kate: All right, Tammy?
Tammy: It's going to come back on the outside of the cup, because on ours it's already starting to do it again, and someone moved it from the edge because it was about to fall off, and her fingerprints are like, they're still like indented in it, so you can tell there's already water in it.
Kate: Okay, thumbs up if you think you're going to notice water on the outside of this cup in the next 8 or 9 minutes, okay?

Tammy brought up an idea that the water would come back on the outside of the cup. Rather than directly responding to Tammy's idea, Kate asked students to vote whether they would see the water on the outside of the cup in about 8 or 9 minutes.

Kate then continued to ask students another question: "Where did the water on the outside of the cup come from?"

Kate: All right, my question is, **where did the water on the outside of that cup come from?** What do you think, Keisha?
K: From the ice.

Kate: Okay, **you think the water is going to come from the ice. How is it going to get from the ice to the outside of the cup?** Keisha, Any idea?
K: Nope.

Students brought up a variety of responses and ideas to explain where and how the water could come from. Kate's ways of responding to students' idea is interesting. To the students' ideas, she kept probing with the follow-up questions with a constant emphasis on "substance tracing."

In the next exchanges, Kate repeated the same questions related to substance tracing.

Kate: Okay, Susan, I haven't heard a thing from you all day either yet. What do you think?
S: The inside of the cup.
Kate: **You think the water is going to come from the inside of the cup. How is it going to get to the outside of the cup?**
S: The ice is going to make the cup cold.
Kate: **You said the ice is going to make the cup cold, and we know that because how many of us have already touched it? Was it cold? Yes, okay, so the cup is cold. So how is the water going to get from the ice to the cold cup to the outside?**
S: Straight?
Kate: **Straight. Okay, it's inside the cup, how is it going to get from in here to out here?**
S: …
Kate: Not quite sure. Okay, that's all right. Keisha?
K: It evaporated?
Kate: **What evaporated?**
K: I don't know.
Kate: Let's make sure we understand that word if we're going to use it. **If there's water on the outside of the cup, Keisha, did it evaporate to get there?**
K: No.

To Kate's substance tracing question, students responded with a variety of ideas: The water would come either from ice or from inside of the cup; the ice would make the cup cold; the water evaporated. With the students' incomplete answers to the question, how does the water get the outside?, Kate kept asking them to think about the possible processes to trace matters, using "How" questions, instead of telling her own ideas or descriptions. Given students' various ideas and responses to her questions, though, Kate did not provide them with her explanations and answers. Rather, she often used the students' terms and descriptions again. For instance, Kate repeated what the students said without adding new idea of her words. She used students' descriptions and words, such as "the inside of the cup," or "the ice is going to make the cup cold," and then asked the follow-up questions. She seemed to build on students' words and ideas to help them realize how condensation happens.

Later, two students came up with more elaborated ideas to explain how the water gets on the outside of the iced cup.

> Kate: All right. Tammy?
> **Tammy: It pulled the evaporated water out of the air and onto the cup, but if it, that's what you said last time that like somebody asked a question about it and you said it took the evaporated water out of the air.**
> Kate: No, because we've talked about this a tiny, tiny little bit about this before in the last unit.
> **Lisa: Since the cup is cold, the air hits it and then it turns back into liquid water.**
> Kate: Okay, and were we able to take liquid water and turn it into solid water?
> S: Yeah.
> Kate: Were we able to take that same solid water and turn it back into liquid water?

The two students showed that they engaged in tracing substance between the air and the liquid water. One student, Tammy, said that the water came from the inside to the air through evaporation. It is interesting to see Kate directly responding to Tammy, saying, "No." The other student, Lisa, then said that the coldness of the object made the air turn into liquid water, showing her understanding of a key scientific pattern of the temperature condition of condensation. Although Lisa did not make it clear whether she meant the water vapor as the air to turn into liquid water, Kate did not clarify that. Rather, Kate elaborated the idea of the changes of state by contrasting two opposite examples, melting and freezing.

Tammy then kept asking another question to Kate.

> **Tammy: How does the water get on there unless it's from the glass?**
> Kate: Lisa?
> **L: There's water in a cup and then the problem was there is water in the cup and how does it get out to there, and then water goes everywhere, and there's water in other places, evaporated water from other things.**
> Kate: Okay, so … water is in lots of places all over the earth, right? So once it gets, does the air just get in one place and then it stays there? Okay, so it moves around? All right, **so water can come from lots of places and just mix in and moves all around, okay?**

Tammy did not seem satisfied and convinced yet with the idea that the water does not come from the inside. Tammy added a sentence, "Unless it's from the glass." Kate had another student, Lisa, respond to Tammy's idea, rather than her trying to answer to her question. Lisa said that the water goes everywhere, so the inside cup is not the one place to evaporate the water. And then Kate built on Lisa's idea and words to say that water mix in and moves all around.

At the end of the lesson, Kate came back to the same question, "where could it (the water) have possibly have come from?" which seems to be the central question that Kate worked on repeatedly. Even when the class dealt with other issues or topics, Kate was conscientious to ask students with the same question, which was substance-tracing question.

> Kate: So where, just a minute, **where could it have possibly have come from then?** Devin?
> D: The air?

Kate: The air, right, we already said where did the water that evaporated go. Up? Right, we kind of watched water boil up and go up into the air and then it looked as if it disappeared, but it didn't just vanish. It broke down into those tiny little molecules of water vapor that we can't see any longer, and now you're saying they come back and now they're on the outside of your cup. Tammy?

Tammy: But, maybe if the water, I know, it's coming from the air, but maybe, um, if you like took my hand or something and I dipped my finger in it, it wouldn't show pink because there's not enough water molecules ... water molecules... to show the color pink, but you put like about that big of a drop so maybe with all of them together it would keep the color of it.

Kate: Take your napkin, one of the Kleenexes and take it inside and touch it. See if we have any color. Just stick your finger down there, soak it up, is there color?

Tammy: Yeah.

Kate: So we can see the color.

To Kate's question, students responded that the water came from the air. Kate seemed to accept this idea, and built on and extended it with more details for the class. However, Tammy refuted Kate's explanation with her own evidence, the color would not show if there were not enough water molecules. She still strongly insisted that the water on the outside of the cup must have color in it, believing the water outside coming from the inside. Kate did not put her down. She did not try to correct Tammy's idea with the correct explanation or idea. Rather, she seemed to let her idea go for the moment.

In the next lesson, Kate began the class with students bringing up their experiences and explanation about the example of condensation, by asking a question, "What happened to the cups last Friday?" The students responded to the question based on their personal observations. Their descriptions of the iced cup included: "the ice melted," "water melted," "the outside of the cup got wet," "there was water on the outside of the cup." And also some students explained, "it changed from solid water to liquid water." Kate then introduced the idea of "heat" as a source of changing the states from solid water to liquid water.

Kate then came back to the central question that the class has worked on since the last lesson: "Where did that water come from?" which was to help students trace substances. The below exchange shows ways in which Kate engaged the students in scientific reasoning.

> Kate: It goes into the air. So, **if there's these little water molecules floating around in the air then, how did it change back into water?** Xanthus?
> X: I don't know.
> Kate: Tammy?
> Tammy: Maybe like it got cold and hit a solid or something and stuck to it?
> Kate: Okay, Salina?
> S: Are you asking how the gas turned into a liquid?
> Kate: Yap.
> S: Condensation?
> Kate: **And what is condensation?**
> S: **When a gas changes from a gas to a liquid.**
> Kate: Okay, and ... in order to change from a gas to a liquid, what has to happen?
> S: Heat.
> Kate: Okay, **in order to go from a liquid to a gas, a solid to a liquid, we know somewhere heat is involved, right? Okay, so going from a gas to a liquid, what are we doing with heat? Are we adding it? Are we taking it away?**
> S: We're taking it away.
> Kate: Okay, why would you say taking it away?
> S: If you were taking it away, it would probably drop back into a liquid.

Based on several students' answers, "it comes from the air," Kate finally led the class to consensus that the water comes from "the air." Kate then continued the discussion with another question, "How did it (the evaporated water) change back into water?" By working on the two types of questions, the students and Kate engaged in scientifically reasoning about why and how the phenomena of condensation take place.

This dialogue shows that it seems like a primary theme of Kate's teaching is to engage students in reasoning about substance tracing of the matter. After Tammy came up with a cold temperature pattern, "the air got cold and hit a solid to be stuck to it," Kate pushed the students more to think about "What is condensation?" The students were able to explain condensation using changes of state, from a gas to a liquid. In addition, by asking a question of whether heat is taken away or added to the air, Kate then led them to think about the idea that heat energy is also involved in the process of condensation.

The exchanges between Kate and her students show that they were engaged in explaining the example of condensation based on theories, such as the changes of state, substance tracing, as well as heat energy transfer. Further, the students' use of scientific terms was correct and appropriate to explain the process of condensation. This particularly contrasts to Sarah's class in that Sarah and her students used vague terms and language without making clear sense of them.

The class then moved on to discuss whether water molecules are in the air.

Kate: Okay, what else do the rest of you think? Does heat have to be involved somehow in this? Ned?
N: Maybe like enough water molecules, they like got together like in the clouds, the water molecules formed together into rain because the little water molecules are really little, and they probably fell to the side of the cup before they went in the air, because the water molecules probably rose up all together.
Kate: Okay, is there water molecules floating in the air right at this second?
S: Yeah.
Kate: Are there always water molecules in the air?
S: Yes.
Kate: Okay, **so where would the water on the outside of the cups come from then?**
C: Water molecules?
Kate: That are **where?**
C: In the air.

Like she did in the first lesson, Kate kept coming back to the central substance tracing question, where and how does the water get to the cup? With the key question, Kate again seemed to engage the class in focusing on reasoning about substance tracing.

The class then began talking about a key scientific pattern, "Temperature condition."

> Kate: Now, let's go back, so we were looking at how did it change then, and we're back to thinking heat, right? Heat's got to be involved somehow. Lisa?
> L: It's um, it's the cold on the cup actually, because the water in the air, it hits the cold cup, and then it turns back into water.
> Kate: Okay.
> S: If it was hot air, then it would evaporate.
> Kate: Okay, **so if heat's causing things to evaporate by adding heat, then to go the opposite direction, are we going to add heat? No, we're going to remove heat, right? So, all of the air that's sitting right around this cup touching that cup… is the side of that cup colder or warmer than our temperature in here?**
> Ss: Colder.
> Kate: You guys have all touched a glass of ice water, it's colder, right? **So the air, the water molecules around that cup right now are heating up or cooling down?**
> Ss: Cooling down
> Kate: Cooling down, heat is being removed, and where does the heat move to?
> S: The air.
> S: No, the cup.
> Kate: To the cup, right, so that **cold cup, if water's going to melt, if that ice is going to melt, what does it need?**
> S: Heat.
> Kate: **Heat, so it's taking heat from the warmer air, right? So the heat's moving, so the water molecules right around that cup are getting colder, and they're changing back from a gas to a liquid.**

In discussing whether the cup is colder than the air to make condensation, Kate engaged students in thinking about the heat energy loss between the warm air and cold cup, and explaining the example of condensation using molecular theory as well. Here Kate exhibited not only that she was tracing substances, but also tracing energy in her teaching. This echoes her sound understanding of the changes of state, substance tracing, and heat energy transfer in the different matters, as shown in her content knowledge interview.

Kate continued the classroom discussion where she set up a situation to help students relate the phenomenon of condensation to another example, the formation of clouds, by helping students make connection between the two examples.

> Kate: Now, my next question is, **what you see here similar to what might be going on in the clouds? What do you think? Could the two be similar in some way? Okay, Chris, what do you think? Can this be anything similar to clouds?**
> **C: No?**
> Kate: Okay, **why would you think it has nothing to do with clouds?**
> C: Because…
> Kate: That's okay. I just, you think that, so there's got to be some reason you think that. Do you see, since you've seen no way they seem to be alike you're just thinking the answer is No?
> **C: Uh, no.**
> Kate: **Why not?**
> **C: Because it's ice, and clouds don't look like that.**
> Kate: Okay, I'm not concerned with "does a cloud look like that blue ice." I'm concerned with what's going on with this ice.
> **C: Clouds don't freeze.**
> Kate: "Clouds don't freeze." Okay, **why would you say that?**
> C: Because if they froze, they would have fell down on us.
> Kate: Okay. Ned?
> **N: Yes, it is like clouds.**
> Kate: And **why do you think it is?**
> **N: Because they like, when uh, it's a whole bunch of them together, it rains from clouds, and when it's a whole bunch of those things, the water molecules from those gather together, it turns into water on the cup, and um, the table, and so that's why it's kind of like clouds.**

To this question, there were some students who strongly refuted the idea, with differing opinions. Chris said there were no relationships between condensation and the clouds, saying "clouds don't look like that (ice)." Instead of directly answering to his answer, she repeated what he said and then immediately responded with "why" questions and then moved on the next students' responses. Other student, Ned, said there were relationships between the two, saying that both of them, clouds and condensation, form the liquid water somehow. Kate kept asking "Why" and "Why not" questions to the students, rather than directly giving them her idea or explanation of whether the two are related.

This kind of teaching practice shows similarity to Diane's and contrast with Sarah's. In Diane's class, Diane was skillful at accepting students' ideas and terms to re-voice them to tell the students what she wanted to address and teach. Kate here shows a different strategy going beyond just accepting the students' ideas and telling them back. She pushed the students to think more about their own ideas by asking why and how questions a lot. In Sarah's class, however, Sarah was good at telling students the correct and right answers and definitions. Rather than building on the students' ideas and words, Sarah often wanted to get the students the scientific ideas, terms, and languages that she believed important, which makes distinction from Kate's teaching practice of advancing students' ideas and thinking.

In the meantime, given the two opposing students' ideas about the relationships between condensation and clouds, Kate seemed to change her teaching strategy for the moment. Instead of continuing the discussion about the relationship between the two, she suddenly made a suggestion for students to make one more observation of what is happening on the iced cup.

> Kate: Okay, um, **without touching the cups, can you just kind of take a quick peek at them and see what you notice right now?**
> S: It's melting.
> Kate: Nope, just try to look at it. **Tell me what you can observe at this time. What can you actually, what do you see,** Jamar?
> J: Water at the top.

Kate: You see that the ice is melting. I said not to touch them. I know, we are going to touch them later, but right now I wanted you just to notice what's going on.

Kate: Daniel, **what did you notice?**

D: It melted.

Kate: **Is there anything else besides the ice melting inside the cup going on?**

D: It's liquid.

Kate: It's changing to a liquid. Anything else? What do you see, Devin?

D: The water is like that.

Kate: **What did you see when you looked at it? What do you see,** Nikia?

N: Little dots on it.

Kate: What are those little dots on it?

S: Molecules?

Kate: **What are those dots? What are all these dots?**

N: Molecules?

Kate: What is it?

N: Bubbles?

Kate: **On the outside of the glass? What is it?** Oh, you're looking on the inside. Maybe you guys need to be a little clearer for me so I know exactly what you're talking about.

N: It's like bubbles and molecules and um…?

Kate: **What do you see on the outside of the glass right now? Anything?**

N: Dots of water.

Students had another chance to re-look at the outside of the colored cups and make descriptions of them. The students described that they noticed little dots on the cup and the melting ice, and explained that they were molecules. Since Kate noticed that some students did not make observations of the outside of the cups, she directed them to carefully look at outside, not inside. The students then described that there were liquid, little dots on the cup, molecules, bubbles, and dots of water. With the students' descriptions and observations, Kate again used the students' words and descriptions to tell them back what they had just said and observed, rather than providing with her own description or words.

Kate then asked students with another question to see if all of the water drops are the same size, by letting them closely look at each of the water drops on the cup.

> Kate: Are all of the dots of water exactly the same size?
> N: No.
> Kate: **Do they look like they're a little bit different sizes,** Xanthus?
> X: Yeah.
> Kate: No?
> X: Yeah, **they look like they're different.**
> Kate: How do they look like they're different?
> X: Some are bigger, some are a lot smaller.
> Kate: Okay, **so you do notice that the droplets of water on the outside are varying in size, right?** Okay, so try to remember that because we're going to look at these again as we go on. Jamar?
> J: I've got to think about it.

Kate explained that the droplets of water on the outside vary in size. It is noteworthy that with one investigation with the colored iced cup, the class was engaged in building multiple experiences to have many chances to carefully look at the cup and describe what was happening inside and outside of cups.

At the end of the second lesson, Kate asked students to bring up other examples of condensation.

> Kate: Okay, **where else have you seen water on surfaces that you didn't spray all over the window. I just hope you guys don't think it's because someone just put it there.** Ned?
> N: On the ground?
> Kate: And **when do you see water droplets on the ground?**
> N: Like in the morning when it's all full of dew and stuff, like dew and snow, and it's melted, the snow is melting.
> Kate: **Go back to dew in the morning. So, on the grass. Where did that water come from?** Did it rain the night before?

Kate engaged the students in relating examples to other examples to find a key pattern of condensation. When Kate asked students to think about another example besides a window, the students began answering with a lot of examples of condensation, including morning dew. Kate wanted students to think about what made the water gathering on the ground in the morning, asking a substance tracing question again, "Where did the water come from?"

> N: It came from the air.
> Kate: And why wasn't it there earlier?
> N: Because of a rapid change in heat, because heat was up and then down at night.
> Kate: So **the temperature became colder at night, and so therefore the water molecules became colder and did what?**
> N: Came down, stuck on the grass just like the cup.
> Kate: But **what did it to in order to stick to the grass and stay there?**
> N: It changed.
> Kate: Changed what?
> N: I don't know.
> Kate: From?
> N: From a gas to a liquid.

A student, Ned, compared the example of the cold iced cup and the morning dew on the grass, making connection between the two different examples of condensation. With Kate's support, Ned seemed to make clear sense of how morning dew could be formed on the ground. Kate added the temperature and heat conditions as key patterns between the grass and the air at night. Ned was also able to explain that the water changed from the gas to the liquid, demonstrating that he engaged in reasoning about changes of state.

Kate pushed her students to think more about another example of condensation, giving them an example of a window, or a mirror in the bath, and asking them to explain why it happens.

> Kate: Okay, **where else have you seen that happen? What if I give you a hint? Who took a shower this morning, anybody? How many then looked in the mirror to dry their hair or brush their teeth, what was wrong with your mirror**, Xanthus?
> X: It was all full of water.
> Kate: Okay, so **why was your mirror full of water? Did you spray it with the shower hose this morning?** Excuse me, listen. **Could you explain that,** Xanthus?

X: The heat from the hot water, it came out of the shower and it hit the window mirror.
Kate: And **what happened when it hit the mirror?**
X: It turned into liquid.
Kate: **Why did it turn into liquid?**
X: …
Kate: **What was the temperature of your water?**
X: Hot.

After Kate gave the students the example of taking a shower with the mirror, the class developed extended discussions about the temperature factors between the mirror and the shower water in the bathroom. Kate engaged the students in reasoning about whether the two objects are relatively warmer or colder to make condensation happen.

With Kate's probing questions in the following exchanges, the students exhibited that they were able to explain condensation well with a scientific pattern, the temperature changes between two objects, and a scientific theory, the changes of state.

Kate: Was it really hot?
X: It was warm.
Kate: What do you think it was? **Compared to hot or cold the water you were standing in the shower? You stuck your hand in the mirror and in the hot shower, same temperature?**
X: Nope.
Kate: Warmer? Was the mirror warmer than your shower water?
X: Kinda.
Kate: Devin?
D: Nope.
Kate: No what?
D: It wasn't hotter.
Kate: What was it?
D: It was colder.
Kate: **So what happens when it hits something cold?**
D: It turns into a liquid.
Kate: **it turns into a liquid because what happened? What happens when it hits something cold?**
D: It turns into a liquid.
Kate: Because?
D: It got cold.
Kate: Because it also became cold, right? All right, Xanthus?

X: Because it didn't have enough heat to stay a gas so it turned back into a liquid.

Students had another chance to think about, and compare, the different temperatures between the object and the air through Kate's detailed support and lead. They engaged in describing the key pattern of condensation, that a cold object and warm air make condensation. While doing so, further, they were also engaged in tracing substances between the gas and the liquid states. Thus, the students seemed to understand the scientific theories and explanations to make sense of the real world examples of condensation.

Overall, in students' observing, describing, and explaining the example of the colored iced cup, Kate engaged the students in developing scientific reasoning through scientific explanations, such as substance tracing, changes of state, and heat energy transfer. At the same time, the students were also engaged in relating examples to other examples to find a key scientific pattern of condensation. Kate's steady lead for the students to use scientific explanations seemed to promote students' making sense of the multiple examples of condensation when they made connections among them.

In addition to this feature of promoting students' understanding through scientific explanations, Kate particularly demonstrated a fascinating teaching strategy to help students develop evidence-based arguments, which takes a different approach to engaging in scientific practice. Kate's teaching practice, based primarily on empirical evidence, is described in the following section in detail.

Kate's Teaching Practice and Evidence-Based Argument

Throughout Kate's teaching practice, Kate often led students' discussion and argument using empirical evidence. Kate was quite skillful at developing the argumentations among students' differing ideas and creating situations where the students came up with various pieces of evidence to support their argument. She often designed and suggested particular activities so that the students could collect the empirical data to develop arguments and discussion. When Kate needed to guide the students toward certain points she wanted them to reach, Kate also brought in and made use of her own evidence to make her argument acceptable?. Thus, this section is to better understand how Kate developed this key theme of her teaching practice for rigorous evidence-based argument.

To help the students understand that the water does not come straight from the inside of the iced cup, Kate used the blue and red colored iced cups. While the students waited to see the water droplets form on the cup, Kate asked them to make prediction of what was going to happen to outside of the cup.

> Kate: What do you predict is going to happen? Devin?
> D: It'll melt and vaporize?
> Kate: What's going to melt?
> D: The ice.
> Kate: What do you mean it's going to vaporize?
> D: It will evaporate.
> Kate: Okay, **do you think you're going to notice enough of a change to know if it evaporated in ten minutes?**
> D: Yeah. ... No.
> Kate: Okay, how long did it take our small little cup to evaporate? Xanthus?
> X: About a week for half of it.
> Kate: **A week, right? In two or three days, how much did it evaporate? Anybody remember when we looked at it just after a couple of days how much it evaporated? Curtis, the directions were to leave it in the middle of the table, not on top of the Kleenex**

and not to touch it. Got to follow the directions. Who remembers after two days? Does anybody remember? Xanthus?

X: It evaporated just a little bit.

Kate: Just a little bit, right? So, Devin, if we only evaporated a tiny little bit in two days, about this much in the cup, you think you're going to notice that ice to melt and evaporate in ten minutes?

D: No.

Devin first came up with the idea that the water would "vaporize." With Devin's idea of vaporizing, Kate reminded students of the investigation they actually did about evaporation before in class, instead of trying to explain or using other ways to refute his idea. She asked the students to remember in the past investigation that evaporation took really long. Using this evidence, Kate argued that evaporation would not be going to happen in ten minutes, with Devin's response that it took about a week for half of the cup of water. Based on Devin's idea and her follow-up questions, Kate led the class in furthering discussion for evidence-based arguments based on their empirical data. Given the evidence that evaporation takes quite long to make water evaporate into the air, the class seemed to be convinced that Devin's idea did not make sense.

When a student came up with an idea that the water inside of the cup directly "jumps" to get to the outside of the cup, Kate followed up with "How" questions.

Kate: Okay, so that's what one single piece of water looks like, right? But back to Xanthus, **you were telling me how did that get to the outside of the cup then? You said that it breaks off, actually you used the word "jump", I used the work "broke off." So where did it come from then?**

X: It broke off and then went to the outside of the cup, and then it turned back into a liquid.

Kate: Okay, so you're thinking that a water molecule is evaporating right off of here, and going right to here. Did I misunderstand that or did I just not put the pieces together quite right?

X: That's what I thought.

It is noteworthy, as described in above section, that Kate consistently came back to the same question of substance tracing question over and over again. Even when the class discussed some other topics, Kate was quite good at pulling the class back to the central question, "How did the water get to the cup?" Xanthus insisted that the water on the cup came straight from the inside of the cup.

To Xanthus's response, Kate developed another evidence-based argument based on the colored cup experiment.

> Kate: Is that what you're trying to say or not quite? Okay, well, we're down to four minutes. I think, wait a minute! **If he was right, just think about this for a minute, what color is my water?**
> X: Red and blue.
> Kate: Okay, if that solid water, you also know what else is inside your cup right now. **There's solid water and liquid water. You can see the liquid water sitting on the outside, can you not? You can see that the solid has gotten smaller, right? (Showing brown paper towel to the class) If I took this piece of brown paper towel, right, made up of lots of little pieces that make up this piece of paper towel, and if I break off a little piece, did the color change?**
> S: No.

Kate showed a brown paper towel to represent molecules to be broken, leading a discussion that if the water comes from inside, then the water outside the cup should have the same color, too, hoping that students could think the water inside is not the same water on outside.

However, as below exchange shows, Tammy did not seem to believe Kate's explanation based on her metaphorical evidence.

> Kate: **So, if water evaporates and I turned it blue or red, when that little piece breaks off, did it change colors?**
> **Tammy: Yeah, it has, we can see it. Actually, it can't evaporate because it's cold, and if it's cold, it's not evaporating. It's not room temperature, because if you feel it, it's warm, it's cold.**
> Kate: Okay, so you think if a little piece breaks off, it changes colors?

Tammy: Well, it most likely wouldn't, like if you go over there and we set it on the heater vent, blowing out warm air, but I would think it evaporate, but it would evaporate like regular colored water, if it had been evaporating down here, it's getting more red than it was earlier, and up here it's more pink. So if it is evaporating, it leaves the other color behind.
Kate: **What I want you to do is from the top, look at your cups, is there water, don't touch the water.** Sorry, I should have made that clear, okay? From the top of the cups, is there water on the top of the cups, raise your hand. **Is there water on your table from where you picked the cup of from?**
Tammy: A little.
S: No.

Tammy rather brought up her own evidence that the color of the water would not move. Tammy's explanation was based on the evidence that heating the colored water would make the color of the water inside darker and denser, indicating the coloring tends to leave inside the cup anyway. With Tammy's suspicion that the water does not come from the inside of the cup, Kate promptly moved on suggesting next activity for students to actually check if there was any color on the outside of the cup.

Students were asked to wipe the water off on the outside of the cup, and discussed what color of water was.

Kate: Okay, some say it's moist. **Will you please take your white Kleenex and wipe the water off of the outside of the cup.** Okay? Okay, that's all right. Well, use one.
S: Maybe just leave enough on your finger to show the color, now that it spilled a little bit.
Kate: Okay, so go ahead and leave that and use this one to clean it off. Table four just spilled, there's the cup of water, just a little bit just spilled out.
Kate: Did that water that spilled out changed color?
S: No.
Kate: **It's still the same color. Okay, so if the water came from inside the cup and went right to the outside, what color would you expect to see on your white Kleenexes?**
S: White, it's white.
Kate: **What color would you expect if it came from inside the cup? Tammy**?

Ta: Pink.
Kate: Okay, **what color is your Kleenex, Lisa?**
L: Pink and white.
Kate: **Okay, from where the water is, it's wet, it's the same color, isn't it? But the other one that you used to wipe off the cup is white, right? So is the water on the outside of the cup then the same water that's on the inside of the cup?**

Some students seemed to expect that the blue or red colors in the water would also appear on the cup. Students wiped the water off on the outside, and based on their empirical evidence they got, interestingly, most students still asserted that the water directly comes from the inside of the cup. They said that the Kleenex showed "White or Pink" colors. Kate then reminded the students that their Kleenex was the colored paper – white or pink. Due to the colored Kleenex they used, Kate was not successful in making the students believe that the water inside does not directly move to outside.

In the next lesson, some of the students still argued that there was the same color on the outside as the inside. The students brought up evidence to support their argument, saying their Kleenex actually had color on it. After a long discussion about whether the water comes from inside of the cup, Kate finally provided students with another piece of evidence to prove their differing arguments.

Kate then had students touch the water outside to check if there was any color on the cup.

Kate: All right, so **here's what I want us to do. I gave each table a Kleenex, please rip it up for the number of people you have in your groups, it doesn't matter if they're exact sizes or not. Quickly, just tear them guys, and I would now like you to touch only the outside of your cups, and I want you to also take a look at the table, okay? Go ahead, each of you wipe one side of the cup.**
Students: (Wiping off the iced colored cups with a Kleenex)
Kate: Yeah, **just wipe it all off. Are your Kleenexes wet?**
Students: Yes, a little bit.

Kate: Okay, is the water colored?
Students: No.
Kate: All right, your cups should be pretty dry by now.
S: Mine has some coloring.
Kate: Whoa, what's all over your table?
S: He spilled it!
Kate: Okay, three, two, one, zero. Whoa, wipe it up please!
Kate: **Okay, did you find water on the outside?**
Ss: Yes.
Kate: **Clear or colored?**
Ss: **Clear!**

Kate provided the students with evidence to support the argument that the water does not come straight from the inside of the cup. So, Kate asked students to wipe off the iced colored cups with a "clean" Kleenex, asking if the water was colored and if they found water on the outside. The students wiped off the cup with Kleenex and said that the water is wet outside. They finally answered that the water on the Kleenex was clear. Given the evidence they got from the Kleenex on the colored cup, nobody in the class seemed to argue any longer that the water came directly from inside.

In the second lesson, based on one of the textbook questions, "What is the temperature of the outside of the cup compared to the temperature of the air in your kitchen?" Kate asked students to make predictions of the temperature, saying, "What do you think the temperature of the outside of the cup is compared to the temperature of the air?" After students were asked to make prediction of the temperatures, one Student, Nikia, responded, two to four degrees on outside of the cup and 20 degrees in the air.

Kate: Is there a way we could find out? If they're close or if there's a big difference between the outside of that cup and the air? Could we answer that question?
N: Yes.
Kate: How?
N: Use a thermometer.
Kate: Use a thermometer... And how would you measure the temperature of the outside of that cup?

N: … put the thermometer on the side.
Kate: Okay. We want to put the thermometer on the side? (Looking for a thermometer in her classroom) I swore my bag of thermometers were right there. All right, um, I'm going to have you do that, Nikia. Let's see with our containers, see if our thermometers are in there either. (Giving a thermometer to Nikia) Tape this like this with these two rubber bands, and this one's going to sit right here. Here's two rubber bands, put the smaller one on the bottom and the bigger one on the top, okay? If you want to put the rubber bands and that's easier, go ahead. If you need help, it looks like you've got it.

Kate asked the class if there was any way to prove Nikia's prediction. This was another set up for making empirical evidence to prove the argument and ideas rather than the teacher's simply explaining without backing it up with any data. Based on Nikia's idea to set thermometers on the iced cup, Kate engaged the class in gathering the evidence to support their prediction. Nikia put a thermometer with a rubber band on the iced cup to check if their prediction was accurate. It is noteworthy that Kate set up another investigation to test the students' ideas and prediction instead of trying to wrap up the discussion based on verbal communication alone. This demonstrates Kate's central teaching strategy to develop classroom discussion and argument around empirical evidence.

Before the end of the class, Kate spent time actually checking the temperatures on the iced cup and the air around the cup.

Kate: **I need Nikia to read out the temperature of the air from the thermometer sitting on the table. Will you please read it for us, in Celsius because you gave us Celsius. Please listen.**
N: 20 degrees Celsius.
Kate: 20 degrees Celsius, whoa, that was a pretty good guess Nikia. That's what you said it would be, right? Can you please tell me what the thermometer is reading on the outside if you can see it, go ahead and pull it up like that. What's it reading?
N: 5 degrees Celsius.
Kate: Whoa, she said 2 to 4, her guesses were pretty good. Well, what do you know about ice?

N: It's freezing.
Kate: And it does that at what temperature?
N: Zero degrees Celsius.
Kate: So when she guessed two to four, she was thinking it's outside, so it's probably just a little bit warmer. Five degrees Celsius, 20 degrees, pretty big difference in temperature?
Ss: Yup.
Kate: Okay, so we definitely know it's a lot colder. We will use that as we look at our clouds and we begin to go into other pieces of our weather unit which will then come back and build back onto this idea of what we have going on here between evaporation, condensation, and precipitation.

Based on the reading of the thermometer, the student's prediction turned out to be quite accurate, showing the iced cup's temperature was 5 Celsius and the air was 20 Celsius.

The feature of Kate's teaching based on the evidence based argument shows that Kate made a habit of looking for support and developing scientific arguments and explanations with empirical data and evidence. Kate made use of lots of evidence to develop classroom dialogues for students' understanding. Her steady use of evidence-based argument seemed effective to help the students realize and overcome their previous ideas. In Kate's classroom, however, it is interesting to notice that the students often did not accept Kate's ideas or explanations without sensible evidence available. Even with empirical evidence, the students sometimes refuted Kate's arguments. With Kate's on-going support to base arguments on evidence, the students seemed to be ultimately convinced by the evidence, not just by the teacher's talk because she was their teacher. Thus, this way of nurturing classroom discourse through scientific argumentation was Kate's central teaching strategy to help students' scientific understanding.

Taking Teacher's Explanations

Kate did not provide the class with a lot of her own explanations, in contrast to Sarah's teaching. Instead, like Diane, Kate was good at building on students' ideas, words, and descriptions, and then elaborated them. At the same time, though, unlike Diane, Kate used classroom arguments, debates, and discussions around alternative ideas. After the classroom discussions, Kate came back to the original main question to provide the students with her final explanations based in her own words.

When a student said that the water molecules inside of the cold cup broke off to get to the outside of the cup, Kate asked how it could happen.

> X: I think that it (molecule) jumps off the cup or something like that.
> Kate: **Well, how these little tiny molecules break off,** okay?
> X: it looks like a Mickey Mouse head.
> Kate: Oh, okay, somebody else said it looked like, **I was going to say I don't remember it looks like Mickey Mouse. What looks like Mickey Mouse?**
> X: The little molecules.
> Kate: **Do you know what kind of molecule you were talking about possibly, has those two little things down here and one here that looks like that Mickey Mouse head? Lisa?**
> Lisa: The head is the hydrogen, and the two little ear things are supposed to be oxygen.
> Kate: Tammy?
> Ta: H2O.
> Kate: H2O, so Lisa, how many oxygens did you give it?
> Lisa: Two.
> Kate: **Two ears, okay, and since you don't know chemical formulas, and you don't know does the two belong to the H or to the O, we're not studying that kind of stuff yet, in middle school you'll be learning some of that, high school lots of that. Actually it's two hydrogens and one oxygen, so somewhere between a little bit you picked up here and Mr. Bates gave it the term or somebody did it looks like Mickey Mouse.**

A student used the term, molecules, and explained the water molecules using a metaphor, "Mickey Mouse head," and Kate demonstrated her way of explaining the abstract idea to the students. Kate did not first try to explain the meaning or definition of the molecules. She asked students to come up with their own ideas of the molecules. After that, building on and using the students' words and ideas, such as Mickey Mouse head, two ears, oxygen, and hydrogen, Kate explained the concept of the molecule with a clarification of what the students said and explained, without throwing out complicated ideas or terms. Thus, about students' ideas that the water molecule, H2O, has 2 oxygen atoms and 1 hydrogen atom, Kate also corrected that the water molecule in a Mickey Mouse has two ears of hydrogen.

Kate's careful job listening to students' ideas looks similar to Diane's teaching practice. Diane also did a good job of being careful to listen to students' ideas to effectively tell what she wanted to teach through re-voicing. On the other hand, however, Sarah did not carefully listen to students' ideas. Instead, she often used scientific language to explain the examples of condensation. Further, Sarah often asked students to copy down what she wrote on the board, whereas Kate and Diane did not ask their students to write down what they said or wrote.

Another feature of Kate's explanation involves her strategic use of classroom debates between students who held differing views, so that she did not have to explain the particular idea. Rather, she built on what they discussed and developed interesting arguments. After re-observing and re-examining the outside of the cup, Kate came back to the original question of whether clouds are related to condensation.

> Kate: All right, back to our clouds. Is there any way that Ned was telling us that yes, this is happening with the clouds as well. Tammy, you are still thinking not. Okay, why?
>
> Tammy: Because it's kind of like Angelo said, and um, if it could freeze or something like that, and if it did, it can't, um, it wouldn't....

Kate: Does it have to freeze to be like what's going on? Is that what we're really focusing on right now, that water freezing?
Tammy: No.
Kate: No, we're more interested in, well, the evaporation more as Salina used the word, the condensation, right? The changing from the gas to the liquid. So, **if we look at just that process, just that event, is that possible in the clouds?**
Tammy: No, because it's not a liquid. It's a gas.
S: You don't know that for sure.
Kate: Okay, **I believe it was Lisa who said she went through a cloud in an airplane and the airplane got wet. So you just said there's liquid in the cloud? Where did the liquid come from?**
Tammy: The air?
Kate: The air, and how did it change to a liquid? Say that louder.
Tammy: It rises.
Kate: okay, air rises, what happens with it rises?
S: It gets cold.
Kate: Okay, **we will be doing an activity to help us with that, so we may need that little bit piece of information to come back. So, if there's water in that cloud, though, it had to come from somewhere, right? And you're thinking the logical place for it to come from is the air.** Salina?
S: Um, I have a question. Are we saying that the clouds are liquids?
Kate: **That's still kind of one of the questions we were debating from last week, what is a cloud?**
S: It's not a gas because you can't see a gas.

Here, Kate led a serious debate of whether the clouds are gas or liquid. A student, Tammy, thought that the clouds are different from the water on the cup. Tammy said that the clouds are made of gas. Thus, this event shows interesting contrast between Kate's emphasis on evidence-based argument and Diane's emphasis on supportive discussion around students' ideas. The other student, Salina, opposed Tammy's idea, saying the clouds can't be gas because we can see them. It is noteworthy here that Kate did not put her words or explanation first, but she was strategically building on students' words, ideas, and descriptions to explain the relationship between condensation and clouds.

S: Okay, they say it's a liquid, but if it's a liquid, couldn't it just pour out, just come down?

Kate: Okay, is the liquid on your glass just pouring down the side of that glass?
S: No.
Kate: I'm not, she's asking a very logical question, right? So if the cloud is liquid, and she knows liquid rain falls, why doesn't that liquid all fall? Do you notice, that's why I wanted you to look at the cups. Did you notice there was water on the tops, the middle, and towards the bottom? And it's not falling, is it? Is it sticking towards the top of that cup?
S: No... Yeah. Yes.
Kate: Why isn't that falling? Tammy?
Tammy: Because it's not heavy enough to drop yet, just like from a cloud, a cloud couldn't be a gas because you said like how it could be like, um, like a drop on an icicle, it won't drop yet, but I asked my mom, my grandma, and my brother about the whole thing we're talking about, and I got the same answer from all of them that a cloud would be a gas at a certain temperature, because it would be like boiling water, maybe it wasn't warm enough.
Kate: So if you could see it, is it a gas?
S: No.
Tammy: But maybe if it was in here.

Kate managed the debate between the two students. Even if Tammy did not seem to totally accept that clouds are made of liquid water, she also seemed to think that a cloud cannot be a gas based on the discussion with Salina. Kate let the discussions go on, helping the students conclude that the clouds are made of liquid.

Throughout managing her students' debate and discussion, Kate helped students develop thinking based on logical argument and building on evidence-based argument, as described above. Kate did not offer her own explanation, nor use her language and teacher voice ahead of students' ideas and description. She was a careful listener to the students' ideas. She always made use of the students' words, ideas, and explanations to build on. That was her primary way of providing the students with her explanation.

Use of Textbook's Explanatory Reading

As described above, in the section about Kate's textbook use, Kate did not spend class time reading the explanatory information in the textbook. Kate said, "It's too easy for them to just look at what's on the picture and memorize what's on the picture, and it's too easy for them to just look at the vocabulary word and memorize the definition, but then they don't understand it." Kate exhibited that her view of science is not based on merely gaining factual definitions.

Given Kate's comments about the informational reading in the textbook, Kate seemed to conceive that reading the explanatory information offered in the textbook would help students' memorization of the factual definition, but not help their scientific understanding. As Kate showed in her teaching practice, she was concerned about the ways to help students make sense of the example of condensation through developing discussion, arguments based on evidence, making multiple observations of the examples, etc. Thus, simply reading the information and factual description did not seem to work as an effective teaching practice for Kate.

There was another set of the reading about clouds right after the condensation activity. The reading included the relationship between condensation and clouds, and the explanation of the different types of clouds. Kate showed her reaction to the reading.

> I didn't get into all the names of the clouds, one, it's not something that our curriculum says our kids have to learn and so… due to time and already being behind schedule, spending a little more time, **I just felt that… what was the real purpose of having them memorize names of different kinds of clouds because I wasn't going to have time to explain why the clouds were different.** I know clouds is a topic they will get to in the middle school where they will look at the different types of clouds and what type of weather and what type of… activity is associated with them, so I just felt that that piece, something had to be eliminated and that was the most logical piece to be eliminated.

Kate asserted that the particular reading section should be eliminated from the textbook. Kate said that she actually eliminated the reading of the clouds, because she thought it would just increase students' memory of the names of the clouds.

This shows that getting students the factual ideas and definitions was not the goal of her science teaching. Kate's decision-making on her curriculum use was based on her critical evaluation of the textbook. She seemed to examine the textbook to judge whether the particular piece of information and activity could be beneficial for students' learning for understanding. As a consequence, contrary to Diane and Sarah's classes, the students in Kate's class did not engage in reading the explanatory information about the three states of the water cycle, evaporation, condensation, and precipitation. Instead, their learning was made through classroom discussion and evidence-based argument without looking at the reading materials.

Assessing Students' Understanding

Kate gave students two types of post-assessments: Drawing the water cycle and a fill-in-blank type of test. The first assessment task was to have the students to draw the diagram of the water cycle. Kate gave the students the names of the terms to include in their drawing. They were evaporation, condensation, precipitation, accumulation, transpiration, water vapor, gas, liquid, H2O, warm and cool. Later, Kate graded students' diagrams. She checked if the students included the scientific terms in the right place and matched well with each step of the water cycle. Most of the students got pretty good scores based on their labeling and drawings.

The second assessment was to give students the blanked sentences to fill in with the scientific terms. The students were asked to match each of the terms to the sentences and write down the terms to fill in the blanks. The examples of the questions include: the water changes from a liquid into _______. The changing of the liquid into a gas is called ________. When the water vapor in the air ________, it changes back into liquid water. The changes of a gas into a liquid is called ________. Kate then gave each student test scores based on the numbers of the correct answers they got. Most of the students got almost perfect scores on the test. There were few of them who got one or two points missed.

From those two types of post-assessment, Kate seemed to focus more on testing if students gained the factual knowledge and definitions. However, considering Kate emphasized that her teaching goal was for students not to learn and memorize the facts of definition in class, this way of her assessing students' ideas looks very contradictory to what she mentioned in the interview before.

Given this confusing contradiction, the post-observation interview gave me a chance to listen to her ideas and goals of enacting these types of assessment. Kate said that the post-assessments were not to assess students' factual definitions.

> Well, on the one side, it was basically vocabulary. And what I did gain from some of this is some of them are still getting evaporation and condensation mixed up because I noticed a lot of times if they missed just two, that was a typical one. Water vapor and some of the students were, that question gave them some problems. But knowing that this is a never-ending circle, **they also do need to explain what is actually happening in each of these little processes and so I think the vocabulary helps me... see if they really understood it. We never just wrote down definitions. I never said, okay, here's evaporation, everybody write out the definitions. Here's condensation, everybody write out the definition, we never did that. Through our discussion I was constantly, what do you mean it evaporated?** What did it do? Change

from a liquid to a gas because heat was added. All along whenever they used that word, what do you mean? So that I knew they were gaining the knowledge themselves, but just sitting and writing out definitions, I never had them do. So by giving them this piece of paper, now, do they really understand those definitions? Can they really put them in the right spots, so that's why I did it. Could I have just given them it and said now go home and memorize these? Yeah. They could have probably all gone home and just memorized them. I didn't tell them that is what I was going to do. I just, this is a, okay guys I've got a quick paper we're going to start the day with. A test? You didn't tell us we were having a test. This is cause it's just a simple little quiz, we've gone through these words 4, 5, 6 times. Over and over, now I want to see who's got them. So they had no idea they were getting it and we never sat down and just wrote definitions and I said go home and memorize them.

Kate stated that in class she never asked students to find out, write down, and memorize the definitions and factual words. She also mentioned, nevertheless, that it is still important for the students to correctly remember the meaning of the terms, by saying, "So by giving them this piece of paper, now, do they really understand those definitions? Can they really put them in the right spots, so that's why I did it." Kate's argument was that even though she did not teach students to focus on the definitions or factual knowledge throughout the lessons, the students still would need to understand the meaning of the words. Thus, regardless of the ways of teaching and learning science in class, Kate seemed to want to make sure that all of the students reached the certain level of understanding and knowledge at the end of the lessons, including the meaning and definitions of the scientific terms.

Commentary on Kate's Teaching Practice and Students' Learning Activities

In teaching practice, Kate engaged students in developing model-based reasoning to make sense of the multiple examples of condensation with the scientific explanations and theories. She created the classroom situation where the students could relate examples to other examples to find a key scientific pattern of condensation.

Kate's key teaching strategy was to develop and make use of evidence-based arguments, which showed her views of science that scientific enterprise consisted of working with data and developing active arguments, debates, negotiations and communications within a community. She used a colored iced cup investigation to provide the students with rich opportunities to gather data and evidence to develop scientific argument and discussion. Kate always looked for empirical data and evidence to help the students engage in logical scientific discussions. Her primary use of evidence-based arguments, which is to engage in practicing scientific inquiry, seemed quite effective to help the students realize and overcome their previous ideas, and develop scientific understanding along with model-based reasoning.

In students' learning activities, students actively engaged in building the personal observation and examples to find pattern of them. They were also able to use the theory of the changes of state to explain condensation, demonstrating substance tracing, engaging in model-based reasoning. With Kate's on-going support to encourage the students to base their ideas with evidences, the students developed good scientific discussions to explain the examples of condensation through making sense of the scientific world.

Reflection in Post-Observation Interview

When Kate reflected on her teaching in post-observation interview, she pointed out that teaching the unit of the water cycle is quite difficult, since there are a lot of difficult abstract concepts to teach the kids who often bear misconceptions.

> I think it's a little bit of a difficult concept to sometimes teach just because there's a lot of areas where the kids can get misconceptions and it's hard to let them really see or feel or get concrete. I believe it needs to be gone over multiple times and as a first time going through the water cycle with this group of kids, I think they did pretty well. I mean, I know I have three or 4 students who understand it pretty well and I have a handful who still have the misconceptions that the water just disappears and they're still mixing a couple of the terms up and then I have another chunk of them in the middle that have some of the pieces and yet there's still a couple of the piece they need to go.

Given her awareness that the particular unit was pretty difficult to teach, my question continued to find out how Kate actually thought about her own teaching practice to help students better understand the abstract ideas by overcoming their misconceptions and conceptual difficulties.

> Shinho: So how did you help them overcome their misconceptions? Did you have some particular ways?
> Kate: Well, I just, **we did demonstrations and then we tried to logically discuss through them. Could this really happen or does it really have to be more like this by giving them other questions for them to realize, well, it can't be. If you can see it, what do you know about a gas, so can this really be water vapor? So, through discussion, through answering other questions, I then try to have them make sense of answering their own questions themselves, internally.**

Given the fact that Kate did not closely use the intended activities and readings in the textbook materials, Kate explained her reasons why the change was important for her teaching and how she modified the intended activity.

> So, **I'm definitely using colored water on the inside, so that they will have proof, evidence, that it's not coming from the glass, or it's be blue, like the water on the inside! It's not blue, so it's not coming through the glass.** So I think that is one key piece that is missing in there, because I know that is just what the kids are thinking. So, to overcome that, I am adding my colored water. Which I think is almost, an important idea. So that is one thing that I did change.

Kate was concerned that the intended activity in the textbook would not be effective to help students answer the two questions of condensation: Did your cup leak? Where did the water come? Kate said that she was looking for some proof or evidence to convince students.

Further, Kate continued to explain why she did not use the readings included in the textbook.

> **I don't give ... I try not to give my kids just the answers. Here it is, it's in the book, read it, and this is it because to me they just kind of look at it and, okay, it's too easy for them to just look at what's on the picture and memorize what's on the picture, and it's too easy for them to just look at the vocabulary word and memorize the definition, but then they don't understand it**, so in my teaching, I have them... putting the stuff down that they know. Having them put the pieces down, having them answer the definitions after they've seen what happens because then I think they understand what they are learning versus me just giving it to them and now memorize this. Because we know anybody can, anybody can do that. They can memorize definitions and memorize that picture for the test and then if you re-asked them again in 3 weeks they would know what you were talking about. I think by having them do it and putting pieces together, then they're putting their own mind, their own files up here and they're going memorize it and learn it more for keep.

Kate said that using the textbook reading itself is not quite helpful for students' understanding. She seems to be concerned about how the textbook materials and activities can help students make sense of scientific ideas instead of memorizing them for test. Thus, overall in Kate's teaching, she did not show much occasions of using the textbook except for some guide questions related to the investigations. Since Kate did not actually follow the same activity in the textbook, Kate and her students did not have to look at the textbook directions or guidelines attached to doing the intended activity.

About the modified activity in condensation, Kate explained why she wanted to use the colored iced cups instead of the regular iced cups.

> When we tried to do the condensation and I used the blue water and the kids just thought maybe the blue wouldn't pick up until someone accidentally spilled something which led us to a whole new idea, well, okay, let's see if the blue shows then, so if the blue showed then when they touched their white Kleenex to it, then if it was going through the cup, the blue would show there. Sometimes things just happen that, well honey, I didn't even really think about that, which then I had to take that idea and get the kids to touch the inside of the cup, and, you know, spill a dab on the table to get them to see that the color is still there, so sometimes things, questions or accidents or things the kids do will change your lesson, the way you originally intended it.

Kate's purpose to use the colored cups was to give students a chance to touch the side of the cup to gather evidence that the water inside does not come straight to outside, mentioning about her teaching strategy.

Overall, Kate demonstrated her view of science that was closely associated with her choice of teaching strategy. Kate viewed science that we develop science through evidence-based argument to develop and use empirical evidences from the activities with classroom discussions to answer the key scientific questions. Kate's another striking point in her view of science was to provide students with the multiple ideas and activities in class to help them build on experiences and examples of condensation and the overall water cycle.

> **Well, I tried to do multiple ideas with them, I mean I tried to go over it two or three times and I tried to get them to really think about, like, the biggest misconception** I think they still hold ... I think they (the multiple ideas) are all important as they need to be able to grab onto as many concrete ideas and enough evidence for them to be able to overcome or gain enough of the knowledge, so... the evaporating water in cups was

> necessary. Could we have done that one again a second time? Probably. Um… the condensation, I think is necessary for them to see that the water didn't really disappear. That it's in the air. I think it's absolutely necessary that the water is colored, which I think, sometimes, you forget, sometimes people just don't think, knowing that what they're going to come up with… uh… the… boiling of the water is just another way for them to see it again that the water will go down, it will completely change so that the water has changed into a gas to get them to understand where did it go. So **I think all those things need to be evidence of them to gain an understanding that Oh! Yeah! This stuff must happen because we're seeing it, we're doing it, and so it's all necessary.**

Kate emphasized that having all of the different activities and ideas would be important for students to have evidence to observe the particular scientific event actually happens. She said that building the multiple examples would help students understand of the scientific phenomena. Kate said that providing the multiple examples contribute to students' developing evidence-based argument is important in her class.

> They have the same ideas to build on in our discussions. If I went home and asked each of them to do those experiences by themselves, some would have come back in not having done them at all, so when they said well this happened, oh no that doesn't happen. **Rita had a lot of different arguments going on because they didn't believe it happened if they didn't see it with their own eyes, so I do it so that we have… we all can see the same things, we all know that that stuff really does happen, we all have the same information for our discussions and to build on, and someone's not always way behind.**

Kate was concerned that the students need evidence to support their argument and discussion. In particular, Kate addressed her major theme of teaching practice is evidence-based argument.

> **What am I doing? I'm letting them think of it and letting them gather the evidence. I'm trying to get them to gather the evidence and make sense of it themselves. I think that's what they need for true understanding. I think for them to really understand and make sense and explain what is really going on, they need all those pieces of evidence to put it together.** If I just give them it, they just memorize it and then they forget about it and next time somebody asks, so what

happens here? Can you explain what happens? They can't explain it because they can't remember exactly how did Mrs. Gray put it.

Kate exhibited her view of science that learners come to understand science through arguments around the conflicting ideas. To Kate, looking for evidence and data was her important part of science learning and teaching practice. She managed science classroom to help students develop scientific discussion and argument. Rather than telling students with the teachers' idea and explanations, Kate sought the idea that students' scientific understanding would be attained through working with actual data, building on their experiences, and developing scientific explanation through classroom discussion and argument.

Conclusion

The case of Kate demonstrates ways in which an elementary teacher with a good scientific knowledge and model-based reasoning provided students with multiple opportunities to learn science for understanding. Her scientific knowledge and practice involved scientific inquiry and application, making connection among experiences, patterns, and explanations. In contrast to the other two teachers, Diane and Sarah, Kate's deep scientific knowledge and understanding played an important role in her ability to modify, develop, and implement the classroom activities.

In the interview, Kate demonstrated good scientific knowledge about finding key scientific patterns in examples of condensation, and made sense of the phenomenon of forming water on the iced cup using scientific explanations and theories. Kate demonstrated model-based reasoning to explain condensation and respond to students' ideas. Her theories included substance tracing, changes of state, and conservation of mass and heat energy.

In teaching practice, Kate engaged students in developing model-based reasoning to make sense of the multiple examples of condensation. After modifying the given textbook activity, she developed a colored iced cup investigation to provide the students with rich opportunities to gather data. Her main teaching strategy was evidence-based scientific argument, closely aligning with her view of science that science develops through evidence-based argument by building data, and on-going negotiation and communication within the scientific community. She looked for classroom discourses in which the students could make sense of real world examples based on the empirical evidence, while they were constantly relating examples to other examples to find a key scientific pattern concerning condensation and construct scientific explanations. Relying on evidence-based argument, which is another form of scientific inquiry, Kate organized classroom discourse to offer students opportunities to make sense of the experiences of condensation.

In students' learning activities, as a consequence of Kate's constant support with her good scientific knowledge and classroom management, students had multiple opportunities to actively engage in building their personal observations and examples to find a key scientific pattern and apply the theory of the changes of state to explain condensation, demonstrating substance tracing, which showed their model-based reasoning. At the same time, with Kate's encouragement for the students to base their ideas on evidence, the students developed sophisticated scientific discussions to explain the examples of condensation through making sense of the scientific world.

Thus, this case illustrates what types of important intellectual resources the elementary teachers need to look for. Kate demonstrated important features of scientific knowledge and practice, and teaching strategies aligned with her views of science, that are likely to result in students' opportunities to learn science. Engagement in inquiry and application through connecting experiences, patterns, and explanations is fundamental feature of scientific knowledge and practice for students to learn science for understanding. Further, like the other two teachers showed, teaching strategies are closely associated with their views of science. Kate's case helps us understand that teacher's scientific knowledge and practice, and their view of science, has an interactive relationship with teaching practice and students' learning opportunities.

Having looked at all of the three teachers' cases, I now turn to the conclusion chapter. I will discuss how teacher's scientific knowledge and practice are related to their teaching practice and students' classroom activities, and argue what types of teachers' scientific knowledge are fundamental for students to have opportunities to learn science for understanding.

Chapter Six: Conclusions

Overview

In the three data chapters, 3, 4, and 5, the stories of three elementary teachers' use of scientific knowledge and practice about condensation were described in three contexts: interviews, teaching practice, and students' learning activities. In this final chapter, I discuss how the teachers in this study understand science and use their scientific knowledge in teaching practice. Based on the findings, I then discuss how we can prepare elementary teachers to effectively develop and use scientific knowledge in their teaching practice. Finally, I propose what it means to have a deep understanding of fundamental science for elementary teachers.

Three teachers' scientific knowledge was closely associated with their teaching practice and particularly with students' learning activities. Each teacher demonstrated that the specific characteristics of scientific knowledge influenced the specific features of teaching practice. For instance, as Diane and Kate exhibited, when they developed a sound personal scientific understanding of a particular characteristic of scientific knowledge, in this case a key scientific pattern in multiple examples, they were able to effectively focus on helping students engage in finding a pattern in examples to make sense of the scientific world. Their scientific knowledge and practice played a role in establishing the important opportunities for the students to understand condensation through finding a pattern in experiences. In contrast, when Sarah focused on listing scientific terms with no elaboration with specific examples and pattern, she ended up having her students gain the factual definitions and authoritative accurate answers from the book sources and dictionary. Her scientific knowledge and practice, which focused more on listing scientific terms, did not allow her to engage her and students in classroom practice that would support them in making sense of the scientific phenomena. Sarah's students therefore had limited opportunities to learn and understand science.

The findings also highlight that teachers' scientific knowledge and practice were not the sole factors that influenced teaching practice and students' learning activities. The important other factors were that each teacher adopted teaching strategies that were consistent with her view of science. Differences in teachers' views of science are associated with differences in their teaching practice and differences in student learning activities and opportunities to learn. However, in our efforts to help teacher candidates and practicing teachers, there are more elements that we also need to consider. They include: teachers' core values and general beliefs about science teaching, teachers' understanding of students, and teachers' professional relationship with others. The consideration of these resources helps us consider how we can prepare elementary teachers to use scientific knowledge in their teaching practice.

Given three teachers' scientific knowledge and practice found in this study, I discuss what it means to have a deep understanding of fundamental science. An important element of scientific knowledge involves the connected nature of scientific knowledge. Making connections among scientific knowledge, experience, pattern, and explanation, is essential for the students to understand the nature of scientific world. Scientific practices, inquiry and application, play a role to help teachers and students connect scientific knowledge to reach scientific understanding of the material world.

Teachers' Scientific Knowledge and Teaching Practice

Based on the findings from the previous chapters, I discuss the characteristics of scientific knowledge and practice that three cases of elementary teachers demonstrated in three contexts: interviews, teaching practice, and students' learning activities. Considering the characteristics of the teachers' scientific knowledge and practice, I then discuss how teachers' scientific knowledge and practice were associated with their teaching practice and students' learning activities respectively.

Given the findings that three teachers chose different teaching strategies, I discuss how their teaching practices were affected by their teaching strategies, which were consistent with their views of science. Each of the three teachers' teaching practices illustrated ways that teachers' ideas about the nature of science become apparent in their teaching strategies. I examine the relationships between a teacher's view of science and her choice and implementation of teaching strategies.

In my discussion of the three teachers' scientific knowledge and practice, I refer back to, and revisit the analytical framework laid out in Chapter 1 (See Figure 1). As shown in Figure 1, there are three types of scientific knowledge: experiences, patterns, and explanations and two types of scientific practice: inquiry and application. Each teacher's knowledge and practice are discussed in three contexts, and compared and contrasted across the three cases.

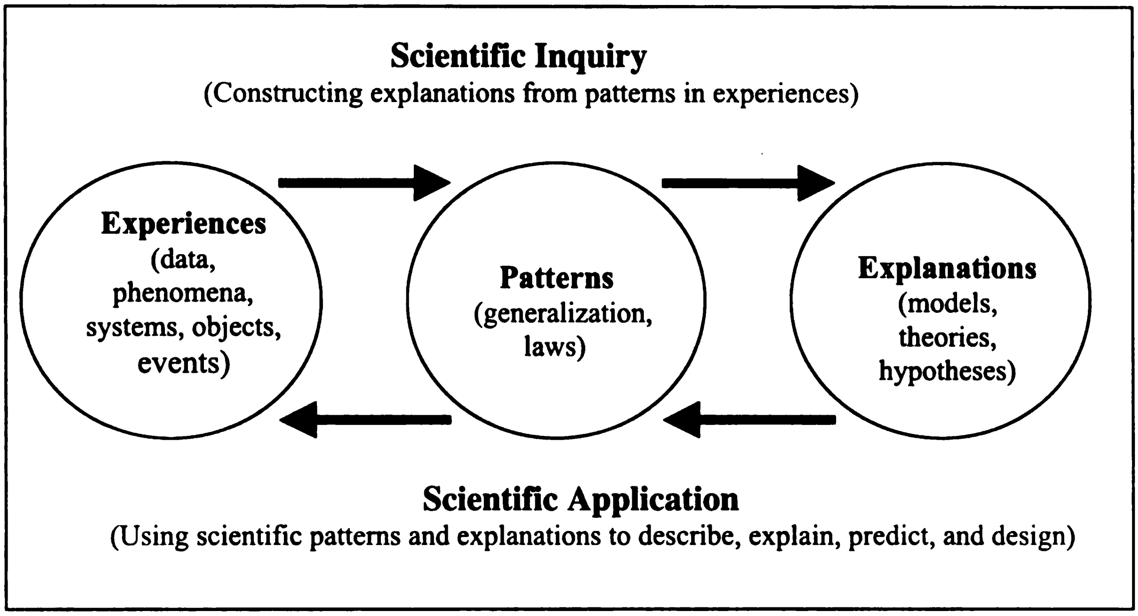


Figure 1. Analytical framework for scientific knowledge and practice

Case 1: Diane's scientific knowledge and teaching practice

Diane held an incomplete yet elaborate understanding of condensation. She showed incomplete understanding of expert scientific explanations, but engaged in deep elaboration with the scientific examples to find a key scientific pattern: the cold object and warm air make condensation. She rarely used scientific explanations and theories to make sense of the examples of condensation, demonstrating incomplete understanding of them. Diane consistently showed the same characteristics of scientific knowledge and practice both in the interview and teaching practice. She demonstrated rigorous elaboration of the examples to find a key scientific pattern, developing a story of the event of condensation based heavily on her personal experience.

In the interview. Diane did not display extensive understanding of scientific theories and models, such as tracing substance, conservation of matter and changes of state. However, Diane elaborated examples of condensation to find a key pattern in them through making coherent connections. She explained the examples of condensation pretty well using a key scientific pattern of condensation, which is the temperature condition: the cold object and the warm air make condensation. Through the whole interview, Diane was successful in telling the story about scientific example and patterns without reasoning about scientific explanation.

In the teaching practice. Diane focused mainly on helping students make personal sense of the key scientific pattern over the several lessons. As in the interview, in her teaching Diane did not make use of any scientific explanations, such as substance tracing, states of change, and molecular theory. Without relying on the scientific theories, though, Diane made sure that students "got" the main point of condensation, "the coldness factor," as a cause for condensation. Diane was quite skillful at telling a story about the conditions necessary for condensation to take place. She developed and told the story of the example and pattern of condensation. However, Diane did not provide the students with the sophisticated scientific terminologies or explanations that she, herself, did not understand, including substance tracing and the changes of state. Instead, Diane thoroughly and rigorously focused on the key scientific pattern that she knew and understood clearly.

In her teaching practice, particularly, Diane repeatedly addressed a key scientific pattern across the several lessons. Diane aspired to help students make personal sense of the example of condensation, ensuring that her students "*get*" the main point of condensation, "the coldness temperature condition of condensation." To do this, Diane made use of a particular discourse strategy that played an important role in effectively conveying to students the main narrative of condensation. Diane's teaching strategy was that she listened and paid careful attention to students' ideas. And then she developed further appropriate reaction to their ideas through "*re-voicing*" them. Rather than directly telling the students the right answer or rebuffing them, Diane was remarkably skillful at "*re-voicing*" students' ideas by putting their ideas into the slightly different ones that she wanted to tell the students. Carrying out this re-voicing strategy, Diane effectively managed the classroom so that students would "get" what kinds of the important scientific ideas the teacher wanted to address.

Diane's re-voicing strategy seemed to be related to her view of science. She viewed science as the process of personal sense-making through experience with the multiple scientific phenomena or activities. Her view of science was neither gaining the factual definitive answer nor accepting authoritative explanation. To Diane, doing and learning science meant to build personal experience to understand the scientific pattern through personal sense-making. During most of the lessons, Diane took the intentional stance to listen to, and carefully and selectively accept students' diverse ideas rather than trying to correct all of the students' ideas. Diane did not accept all ideas equally, though. Thus, when she provided her explanation about condensation, she chose the re-voicing strategy, which allowed her to value the students' ideas while also allowing her to help the students make sense of the important scientific pattern of condensation.

In students' learning activities. Students engaged in observing and describing the examples of condensation, and relating examples to other examples. Throughout the classroom activities, the students were able to describe and discuss the scientific pattern in examples, which was "cold object and warm air make condensation," showing the similar characteristics of Diane's scientific knowledge in interview and teaching practice. However, they rarely had any chance to learn another form of scientific knowledge, which is scientific explanation, such as substance tracing. Thus, the students gained experience by elaborating examples to find the scientific pattern of condensation, but they did not engage in scientific explanation, nor did they have the opportunity to learn other theories or models, such as tracing substance, conservation of matter, and changes of state, to explain condensation.

In summary, Diane exhibited a coherent pattern of scientific knowledge and practice between her interview and the classroom teaching practice, which was to make the connection between experiences and an identified scientific pattern. This characteristic of scientific knowledge and practice were similarly shown in the students' learning activities as they engaged in scientific reasoning about examples and scientific pattern. With Diane's support, the students certainly had opportunities to learn science through practice with finding scientific patterns through the use of examples. Further, Diane's re-voicing strategy and view of science seemed quite influential on shaping students' opportunities to learn, since the students were effectively engaged in developing a scientific account of the key scientific pattern of condensation.

Case 2: Sarah's scientific knowledge and teaching practice

Sarah exhibited about the same scientific knowledge and practice as Diane. Like Diane, Sarah accurately found a key scientific pattern, temperature condition of condensation, in various examples. In contrast to Diane, Sarah added and used a wide range of the scientific terms to make sense of condensation. She tried to explain condensation using many scientific terms instead of using experiences and the scientific pattern. However, she was often vague about the nature of the gas when explaining the changes of state. This pattern of practice was consistent both in her interview and her teaching practice. As shown in her teaching practice, Sarah's major approach to understanding condensation was devoted to listing and expanding her use of the scientific terms.

In the interview. Sarah did not use her understanding of experiences and a key pattern to explain condensation. Rather, she often used a number of the scientific terms, such as molecules, vapor, air, hydrogen, oxygen, heat, energy, and gas. She did not show clear understanding of the underlying meanings of the particular terms, blurring the concepts of gas, vapor, air, etc. When she explained condensation, related examples to other examples, and responded to students' ideas, her limited understanding of the changes of state without substance tracing seemed to contribute to her superficial understanding of the scientific explanation of condensation.

In the teaching practice. Sarah's scientific knowledge, as demonstrated through her teaching, matched with the knowledge displayed in her interview. She spent little time encouraging students to make observations and develop descriptions of the phenomenon of condensation, limiting their opportunities to work on experience and pattern. Instead, Sarah engaged students in gaining lots of scientific terms by asking them to look up words in the dictionary to find the definitions of the terms, e.g. molecule, air, gases, hydrogen, and oxygen. Using the scientific language, she also expressed the idea of the changes of state, but her explanation was unclear without substance tracing reasoning.

While Sarah employed lots of the scientific terms to explain the examples of condensation to students, she relied on a teaching strategy to help students frequently use the dictionary and textbook to acquire the correct factual knowledge of the terms. She developed some games, such as finding the definitions in the cards, and tasks, such as a crossword puzzle, to help students to learn the specific terms. Sarah did not provide the students any experience with the scientific phenomena in order that they might find the pattern in them. Due to Sarah's consistent focus on gaining the definition of the scientific terms, the students were engaged in using the dictionary to master the definitions of the scientific words. Sarah's teaching did not seem to help the students make sense of the material world, except for gaining the meaning of the scientific vocabulary.

Sarah viewed science as accumulating the accurate meanings and definitions of the scientific terms, showing her respect for authoritative scientific facts. To her, understanding science constitutes gaining a repertoire of accurate scientific terms. As shown in her classroom teaching, Sarah emphasized gaining the literal understanding of the language, as she said in the interview, "They had to know what the words were, if they didn't know what the word was they had to use the dictionary to look it up." While the students worked on refining and rebuilding the scientific words, they did not have any chance to work with the examples to find patterns and construct or use the scientific explanation beyond the literal definitions.

In students' learning activities. Students were engaged in acquiring the definitions of the scientific terms. They were given limited chances to make observation and description of the examples of condensation. Since the students were expected to listen to Sarah's explanation about the various scientific terms and then look up the meaning of the scientific words in the dictionary and textbook, they had limited opportunity to make personal sense of the material world by building experiences to find a scientific pattern. Thus, they did not seem to have any chance to make personal sense of the scientific phenomena, as opposed to Diane's or Kate's class.

In summary, Sarah had a good understanding of experiences and a key scientific pattern along with a wide range of the scientific terms about condensation. But, in teaching practice, her scientific knowledge and practice turned out to focus heavily on listing the unclear scientific terms to explain condensation to students, rather than helping the students find a key pattern in experiences. This resulted in superficial coverage of a wide and broad scope of scientific terms. Students developed an incompatible and incorrect understanding of these terms. They were able to list lots of the scientific words without having opportunities to engage in scientific practice, inquiry and application for scientific understanding.

Thus, the opportunities Sarah's students had were to engage in increasing their factual knowledge through gaining the authoritative correct definitions of the terms without making sense of the scientific phenomena of condensation. These opportunities arose from the pedagogical decisions that Sarah made based on her view of science.

<u>Case 3: Kate's scientific knowledge and teaching practice</u>

Kate demonstrated thorough scientific knowledge and understanding about example, pattern, and scientific explanation. She made intimate connections among those scientific concepts through elaborating scientific explanations with experiences and patterns. Both in the interview and in her teaching practice, Kate showed a consistent pattern of making connections among scientific knowledge through engaging in inquiry and application. Both in the interview and in her teaching practice, Kate was quite successful in explaining the examples of condensation and responding to students' ideas, using scientific theories and explanations appropriately.

In the interview. Kate demonstrated good scientific knowledge, including scientific theories, such as substance tracing and the changes of state. She related examples to other examples to find key scientific patterns of condensation, and she explained the examples of condensation using scientific explanations appropriately and accurately. Kate made scientific sense of the example of forming water on the iced cup through making rigorous connections among example, pattern, and scientific explanations. When she explained the examples of condensation and responded to students' ideas, Kate exhibited her good understanding of the process of condensation. For instance, she differentiated sweating from condensation based on her idea of substance tracing. Kate's reasoning about how the water gets on the cup was also consistent with her sound explanation of the examples of condensation.

In the teaching practice. Kate engaged students in developing scientific understanding of the multiple examples of condensation, demonstrating the same feature of scientific knowledge shown in the interview. She used a scientific activity, a colored iced cup, to provide the students with the opportunities to observe and experience the example of condensation. In discussing the examples of condensation, Kate helped them relate examples to other examples to find the key scientific pattern of condensation. Further, Kate guided the students to scientific application by engaging them in applying the scientific explanation, substance tracing, to make sense of the process of making the water on the cold cup. She created a classroom situation where the students could relate examples to other examples to find a key scientific pattern of condensation.

Kate employed a teaching strategy of encouraging students to develop and engage in evidence-based argument. To carry out the strategy, she set up a colored cold cup investigation for the students to gather data to use as evidence to support their logical argument and to make sense of the particular phenomena. She encouraged the students to actively discuss and argue based on their own observation, data, and theory. Kate's choice of evidence-based argument was very effective in helping the students discuss a variety of ideas about the particular scientific event and develop scientific understanding, while working on model-based reasoning simultaneously.

Particularly, Kate set up the problem as choosing alternate hypotheses, which also become an argument between people who support the alternate hypothesis. For instance, Kate formulated two hypothetical situations to explain where the water on the iced cup comes from. She gave the students two choices, either the water comes straight from the inside cup, or from the air somewhere. To promote arguments around the two opposing hypothesis, she used the colored iced cup so that the students could build evidence to support their arguments.

To Kate, developing scientific evidence through collecting data and making observation acted as the important aspect of doing and learning science. By mentioning in her interview, "I think for them to really understand and make sense and explain what is really going on, they need all those pieces of evidence to put it together," Kate seemed to believe that science begins with examples and experientially real data in a real world situation. Another view of science that Kate seemed to hold is that scientific practice is accomplished through disagreement, argument, and discussion among peers. Despite the possibility that this view of science would be problematic for some students, Kate set up the classroom discourse so that the students could develop discussion and arguments around the competing local theories. To her, it seemed to be important to develop the awareness that scientific knowledge develops through competition and negotiation among different opposing ideas and theories, rather than simply accepting one dominant view or idea.

In students' learning activities. Students were actively engaged in personal observation of examples in order to find patterns in experience. With Kate's support, the students were able to explain condensation using the theory of the changes of state and substance tracing. With Kate's consistent emphasis on discussing the phenomena using empirical evidence, the students were engaged in carefully observing and describing the colored iced cup investigation, and explaining the examples with scientific explanation. Thus, the students were engaged not only in constructing scientific explanation based on their personal observation and scientific pattern in experiences, but also in applying scientific explanation to the real world example of condensation.

In summary, based on her deep understanding of scientific knowledge, Kate established the opportunities for students to increase their understanding of condensation through observations and discussion of examples to find a key scientific pattern. With Kate's consistent support, her students were able to trace substances to explain and make sense of the examples of condensation. Kate's teaching strategy to enact evidence-based argument played a role in facilitating students' scientific reasoning based on empirical evidence and data, and in supporting logical argument about the discrepant events she carefully provided. She provided her students with rich opportunities to learn science concepts and to share their differing views of the scientific world.

Comparisons of three cases: Differing scientific knowledge and differing teaching practice

Teachers' scientific knowledge and teaching practice. I found compelling contrasts in the three cases of teachers' scientific knowledge and practice. The different types of scientific knowledge and practice the teachers had led them to provide different opportunities for students to learn science (See **Table 2**). So, to come up with similarities and differences, I briefly revisit how each of them exhibited different knowledge and practice.

In the interview, Diane and Sarah's scientific knowledge and practice have important similarities and differences. On one hand, both of them were able to list the examples of condensation and articulate a key scientific pattern in examples, which was the temperature condition of making condensation, demonstrating narrative and practical reasoning. On the other hand, they showed differences in terms of their knowledge and use of scientific explanation, and their ways of using examples to find a pattern. Whereas Diane focused rigorously on the temperature condition to develop a good account of the example of condensation, making intimate connection between experience and pattern, Sarah focused loosely on reasoning about the examples and pattern in condensation. Instead, Sarah used a wide range of the scientific terms that she sometimes did not clearly understand, including her use of gases along with her idea of substance tracing. Despite her articulation of scientific patterns, Sarah rarely used examples or scientific pattern to

Table 2. Comparison of the Three Cases: Scientific Knowledge and Practice

	Interview	**Teacher's Teaching Practice**	**Students' Learning Activities**
Diane	• **[Experience]** List examples • **[Pattern]** Find a key scientific pattern in examples • **[Explanation]** No use of scientific explanation 1—See Notes **E ←→ P ---- (E)**	• **[Experience]** Provide examples • **[Pattern]** Help students find a key scientific pattern in examples • **[Explanation]** No use of scientific explanation **E ←→ P ---- (E)**	• **[Experience]** List examples • **[Pattern]** Engage in finding a key scientific pattern in examples • **[Explanation]** No chance to use scientific explanation **E ←→ P ---- (E)**
Sarah	• **[Experience]** List examples • **[Pattern]** Find a key scientific pattern in examples • **[Explanation]** List lots of scientific terms – the changes of state without substance tracing **E ←→ P ---- E**	• **[Experience]** Less emphasis on providing examples • **[Pattern]** Less emphasis on engaging students in finding patterns • **[Explanation]** List lots of scientific terms – the changes of state without substance tracing **(E) ---- P ---- E**	• **[Experience]** Less emphasis on building and observing examples • **[Pattern]** Less emphasis on finding patterns • **[Explanation]** List lots of scientific terms without accuracy – look up dictionary **(E ---- P) ---- E**
Kate	• **[Experience]** List examples • **[Pattern]** Find a key scientific pattern in examples • **[Explanation]** Accurately apply scientific explanations to makes sense of condensation – substance tracing **E ←→ P ←→ E**	• **[Experience]** Provide lots of examples • **[Pattern]** Find a key scientific pattern in examples • **[Explanation]** Use of scientific explanations and theories with accuracy – substance tracing **E ←→ P ←→ E**	• **[Experience]** Engage in experiencing the multiple examples • **[Pattern]** Find a key scientific pattern in examples • **[Explanation]** Use of scientific explanations and theories with accuracy – substance tracing **E ←→ P ←→ E**

<NOTES> ←→ represents "Making connections" between scientific knowledge
----- represents "weak" connections between scientific knowledge
( ) represents "Less use" of the scientific knowledge

make sense of the phenomenon of condensation, making less connection between experience and pattern. In contrast, Kate exhibited good scientific knowledge of condensation. She was able to distinguish various types of science knowledge, experiences, patterns, and explanations, and find patterns in experiences to develop scientific explanation. She exhibited applying the scientific explanation to the real world examples of condensation.

In their teaching practice and students' learning activities, each of the three teachers showed that their scientific knowledge and practice echoed their teaching practice and shaped students' opportunities to learn science in various ways. Diane successfully engaged students in making personal sense of the scientific pattern in various examples. She was successful in helping students find the key scientific pattern without relying on scientific theories and explanations. As shown in the interview, Diane also engaged her students in developing a scientific account of the key scientific pattern in various examples, helping them make connection between experiences and pattern. In contrast, Sarah told a story about condensation around various scientific terms. She engaged her students in covering the various scientific words without making sense of the scientific examples, pattern, and explanation, which resulted in a procedural display of factual knowledge by the students. Kate engaged students in making sense of the examples to find patterns and developing scientific explanation through substance tracing and the changes of state. The students were engaged in making consistent connection among examples, pattern, and scientific explanation. Based on her personal scientific sense-making, Kate provided her students with lots of opportunities to make sense of the examples and scientific pattern using substance tracing theory and the changes of state.

Furthermore, the teachers' scientific knowledge had a profound influence on their teaching practice and particularly on students' opportunities to learn science. As Diane and Kate exhibited, when they developed a good personal scientific understanding of a particular characteristic of scientific knowledge, in this case a key scientific pattern in multiple examples, they were able to effectively focus on helping students engage in finding a pattern in examples to make sense of the scientific world. Their scientific knowledge and practice played a role in establishing the important opportunities for the students to understand condensation through finding pattern in experiences. For example, when Kate helped students engage in scientific explanations of the examples of condensation based on her sound scientific knowledge and understanding, her students were actively engaged in explaining why and how the water forms on the cold iced cup. Kate certainly provided students with an important opportunity to learn how to make sense of the scientific world.

In contrast, when Sarah focused on listing scientific terms with no elaboration with specific examples and pattern, she ended up having her students gain the factual definitions and authoritative accurate answers from the dictionary. Her scientific knowledge and practice, which focused on listing scientific terms, did not allow her to engage herself and students in classroom practice that would support them in making sense of the scientific phenomena by finding a key scientific pattern in examples and applying scientific explanations and theories accurately and adequately. Sarah's students therefore had limited opportunities to learn and understand science.

Teaching strategies, views of science, and teaching practice. In addition to teachers' scientific knowledge and practice, teachers' teaching strategies were associated with their views of science turned out to be another important factor influencing students' learning activities. Differences in teachers' views of science are associated with differences in their teaching practice, and differences in students' classroom activities and opportunities to learn. The teaching practices of the teachers in this study were influenced and guided by the view of science that each of them held.

For instance, with Diane's view of science as developing personal sense through finding patterns in personal experiences, Diane used a re-voicing strategy to build on students' local ideas. Diane's use of a re-voicing strategy was effective in inviting students' ideas and in informing the students of the important scientific ideas and stories. With Kate's view of science as building evidence-based argument, Kate provided students with rich opportunities to observe the example of condensation and to gather data to develop arguments based on scientific reasoning. Kate's use of an evidence-based argument strategy played a role in helping students develop the scientific practices of gathering empirical data to find patterns and constructing logical arguments to explain real world phenomena. In contrast, with Sarah's view of science as gaining a repertoire of accurate scientific facts, Sarah employed a way of helping students to expand their understanding of the scientific words with the correct definitions. Sarah's use of the dictionary to build scientific vocabulary did not seem conducive to students' scientific understanding and reasoning, limiting the students' opportunity to understand science.

Implications

The stories of three teachers in this study, Diane, Sarah, and Kate, provide insights into how we can prepare elementary teachers to use scientific knowledge in their teaching practice for enhancing students' opportunities to learn science for understanding. The three teachers engaged in different scientific knowledge, practice, and approaches to making sense of condensation, which were associated with different quality and types of students' learning activities. Based on the three teachers' different choices to make sense of condensation, I discuss an important implication for science teacher education related to what it means to have a deep understanding of fundamental science. I propose ideas about teacher education that can help teacher candidates develop similar important knowledge and teaching practices.

What Kate and Diane knew that helped them teach: a deep understanding of fundamental science

I argue that model-based reasoning, as Kate exhibited, is the most effective reasoning skill for elementary teachers to understand the scientific phenomena and develop teaching practice for students' scientific understanding. Model-based reasoning requires the ability to make coherent connections among scientific knowledge based on a deeper level of conceptual understanding of each component of the knowledge. Understanding of scientific explanations and expert propositions of theories is the basis of the reasoning.

In particular, in elementary teaching for students at earlier grade levels, model-based reasoning promotes students' scientific reasoning through practice with explaining the examples and activities using "why" and "how" questions. To do so, elementary teachers need to introduce an appropriate degree or level of models and theories to the students. For instance, Kate engaged students in explaining the water on the colored iced cup using substance tracing. She did not have to introduce the higher, more advanced level of molecular kinetic theory to the students. Instead, Kate engaged them in an appropriate level of models and explanations, using a less sophisticated and lower level of substance tracing, which included macroscopic understanding of gaseous water (water vapor) turning into the liquid water due to the changes of state. Kate found an appropriate level of scientific explanation to help the young students be able to explain the scientific world and precisely reach scientific understanding of the reasons that the material world works this way.

However, we also need to seriously consider the reality in elementary science education. All of the elementary teachers do not have the same quality and high level of subject matter knowledge as Kate exhibited. Many elementary teachers often do not have basic understanding of scientific ideas (Abell & Smith, 1994; Smith & Anderson, 1999). Given the reality in elementary science, how can we teach science without deep understanding of the subject matter? Of course, we can argue that the teachers would need more subject matter knowledge and conceptual understanding in order to teach science more successfully with model-based reasoning. This is true, but we also know that this solution is not always feasible and plausible to most elementary science educators.

Given the situation in elementary science, therefore, the case of Diane particularly gives us an important idea to support other science teachers who hold incomplete and less extensive scientific knowledge and understanding. It is noteworthy that like Kate, Diane was also successful in engaging students in understanding a key scientific pattern in spite of her less extensive scientific knowledge and understanding. The examples of Diane's teaching gives us a view of what is possible for elementary teachers who do not have sound subject matter background and who are unfamiliar with scientific theories, models, and expert propositions.

Thus, as Diane exhibited in this study, I argue that engaging in making close connection between experience and pattern can allow a teacher to make sense of the scientific examples based on personal experience and to compensate for his/her inability to rely on scientific models. With the teacher's support, students can then be engaged in understanding what scientific pattern can be found with rigorous and thorough understanding about the particular events and examples. By doing so, the students can have opportunities for engaging in attaining an important aspect of scientific understanding, which is to find and make sense of a key scientific pattern in various examples they built around their home and classroom.

Given the scientific knowledge and practice that Kate and Diane exhibited, I now discuss what it means to have a deep understanding of fundamental science for elementary teachers. Teaching for scientific understanding involves engaging teachers and students in learning types of scientific knowledge, which are examples, patterns, and explanations (Anderson, 2003). More importantly, making connection among those types of scientific knowledge is important for the students to understand the scientific world. Thus, teachers need an understanding of the connected nature of scientific knowledge among experience, pattern, and explanation.

There are two effective ways to make connections through scientific practice: scientific inquiry and scientific application. First, scientific inquiry involves finding a pattern in examples to construct scientific explanation. Second, scientific application involves using the scientific explanations to explain and make sense of the real world examples. Engaging in these two scientific practices is an effective way to make connections in scientific knowledge, accomplishing what is called as compatible-elaborate understanding (Hogan & Fisherkeller, 1996).

Model-based reasoning, as Kate demonstrated, is a useful reasoning skill to make sense of the scientific world and help students make sense of scientific examples based on deep scientific knowledge and practice. Scientific explanations or expert propositions play a role in scientifically understanding and explaining real world phenomena. Understanding, using, and applying scientific explanation is important to gain scientific understanding by explaining the real world examples for scientific understanding. In elementary science teaching, in particular, finding, appropriating, and using the proper level of model or scientific explanation would contribute to teaching for scientific understanding. In elementary science, elaboration with specific examples is a useful practice that can help students find a scientific pattern. The teacher must provide the students with enough opportunities for observation so that they can make personal sense of the examples. Further, I also argue that to augment the effectiveness of teaching practice, elementary science teachers certainly need other intellectual resources, which include teaching strategies and views of science for helping students learn science.

Ideas about elementary science teacher education

In working with elementary teachers in the teacher education program or professional development program, we consistently face challenging questions. What specific types of scientific knowledge and practice do we need to help the teachers develop? What kinds of teaching strategies and views of science do we need to help them develop? How can we help them develop the important intellectual resources along with an understanding of why we need them and how we employ them? These are the important questions we as elementary teacher educators consistently encounter.

This study contributes to our ideas about teacher education by providing us with possible implications to the questions. When we prepare preservice elementary teachers in teacher education program or train practicing teachers in various professional development programs, we need to help the teachers have rich experiences to build a deep understanding of the fundamental scientific knowledge and skills. It is important to note that the types of learning opportunities provided to students depend on the close associations among teachers' knowledge and skills developed through the various programs. As this study found, these resources are: understanding of the connected nature of scientific knowledge, model-based reasoning, and effective teaching strategies that are aligned with a teacher's view of science. These intellectual resources are what we need to emphasize in elementary science teaching. This type of scientific knowledge is different from gaining or covering mastery of a list of a variety of the scientific knowledge and propositions. Our job as teacher educators is to keep developing ideas of how to help the teachers understand the essential nature of scientific knowledge and practice through the programs.

Further, in our efforts to help teacher candidates and practicing teachers, there are other important elements that we also need to consider. They include: Teacher's general core values and beliefs about science teaching, teachers' understanding of students, and teachers' professional relationship with others.

Teachers' core values and beliefs are the important elements that shape their teaching practice. Different teachers have different values and beliefs: teaching the important science content, making class fun and interesting, gaining respect from the students, preparing students for the test, etc. These are not mutually exclusive, but teachers put different priorities on the various values of science teaching. Teachers' understanding of their students is another important factor that affects teaching science. Teachers' assessment of students' understanding and learning influences their curricular and instructional decisions. Some teachers assess students to give them grades and scores on the test. Others assess students' learning to qualitatively understand students' conceptions and scientific reasoning. Teachers' professional relationships with others are also essential parts of forming teaching practice. There are various ways for teachers to interact with others: conforming with expectations of other teachers, such as teacher education instructors, and mentor teachers; gaining status and respect; making personal connections with others; and sharing resources and ideas about teaching and learning.

Furthermore, I argue that teachers' habits of mind play a pivotal role in the successful enactment of all of the important elements of knowledge and skills. Curiosity is something that teachers need to seek in order to develop, construct, and refine their scientific knowledge and skills so that they can teach science better for students' understanding. Their motivated desire to improve the intellectual resources is the key to success in teaching. Rigor is another critical component in teaching practice that can help students make sense of science. Given the resources the teachers have, it is important that they make rigorous use of their knowledge to enact instructional ideas and plans that allow them to teach for understanding.

Finally, it is an enormously daunting and challenging task to help our elementary teachers to attain all of the intellectual resources or elements necessary for supporting students' science learning. Nevertheless, it is still our important job as teacher educators to come up with better ideas and ways to help teachers gain a deep understanding of the fundamental scientific knowledge and practice, along with effective teaching strategies, views of science, general core values and beliefs, understanding of students, professional relationships with others, and habits of mind.

Limitations of the Study

Teaching and learning are complex businesses (Cohen, 1988; Lampert, 1985, 2001). This study addressed the question of how teachers' scientific knowledge and practice are associated with their teaching practice and students' learning activities. But, this study has several limitations, which should be noted.

I pointed out and examined several important intellectual resources or factors that influence teachers' teaching practice. There are undoubtedly other important variables related to science teaching that this study did not address, including teachers' habits of mind. Although I briefly mentioned habits of mind in the implications section, this study did not clearly look at what habits of mind the teachers had and how these habits influenced their teaching. More importantly, there are also other factors, such as beliefs and practices about students, classroom organization, teaching strategies, etc. There may be external factors that affected their teaching as well. Other stakeholders, such as policy makers, curriculum developers, school administrators, other teachers, parents, etc. also have significant influences on teachers' teaching activities and particularly their ways of teaching science with certain goals. This study did not consider these possible external influences.

Another complexity stems from the relationship between teachers' teaching and students' learning. In this study, I made a weaker case that the differences in students' classroom practices and opportunities to learn are likely to result in students' different learning. I think that the case is not strong enough, though, to justify students "learned" or "gained scientific understanding." Since this study did not examine students' learning and understanding, and compare their learning in different teachers' classrooms across the cases, it is hard to make a generalization that one teacher did a better job than another teacher in supporting students' learning.

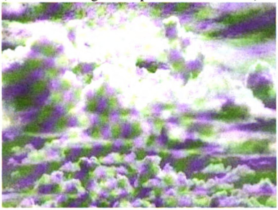
Further, to analyze teachers' teaching practice and activities, I focused more on the teacher's side. Although I also examined students' learning activities, I sought teachers' intellectual resources as main factors to influence both their teaching and students' learning. The study did not extensively collect students' data particularly about their motivation or attitude to learn and various propositions about science learning. Since the students' individual factors likely interact with teachers' teaching practice and influence the effectiveness of teaching and learning science, more focus on the students' side might be needed for future study.

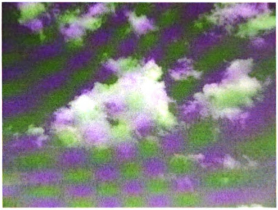
Appendix A. Interview Instruments

1. Science content interview protocol on the Water Cycle

[Clouds and Precipitation]

(After showing these pictures of clouds)





I. Subject matter knowledge interview

1. What have you noticed when you watch clouds?
2. What are some things that you know about clouds?
3. What do you think clouds are made of?
4. Can you clarify states of water? Which ones are there? Which ones do you see?
5. Where does water in clouds come from?
6. How do they stay up in the air?
7. Would you expect rain from these clouds? Why or why not?
8. What is the difference between rain clouds, snow clouds, and regular clouds? How do they form? What happens to them?
9. What are some things you know about rain (and snow)?
10. Where does the water in rain (and snow) come from? What was it before it was liquid water (and iced solid)?
11. How are the formation of rain and snow alike and different?

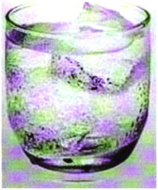
II. Scenario

Imagine that your students are excited about their findings about clouds, rain and snow. How would you respond to each of the students' ideas? What would tell them about their ideas?

a. Jon: Clouds are made of water vapor.
b. Mike: Clouds are light and warm to fly around in the air.
c. Nancy: Clouds are made of ice crystals.
d. Phil: There are little holes in the clouds that let the rain out.
e. Bill: Snow falls when the clouds get cold.
f. Joe: The clouds move into the sea or ocean to collect water to make rain.

[Condensation on outside of cup]

(After showing a picture of the iced cup)



I. Subject matter knowledge interview

1. What do you think will happen to the ice inside the cup? Why?
2. How do you think the weight of the water from the ice melting will compare with the weight of the ice? Why?
3. What would happen to a balance of the iced cup as time passes by?
4. What would happen to the outside of an iced cup?
5. Can you think of other times when something like this happens?
6. Where do you think the moisture on the outside of the cup came from?

Was it something else before it was liquid water? What?

II. Scenario

Let's spend some time considering some students' ideas about this classroom event. How would you respond to the students' ideas? What would you tell them about their ideas?

a. Jane: The iced cup is sweating.
b. Paul: The water outside of the cup comes from inside of the cup.
c. Carl: The water in the air moves to the outside side of the iced cup.
d. Mary: Hydrogen and oxygen in the air are water on the cup.
e. Joe: Water is evaporating from the water in the cup and condensing on the outside of the cup.

[Evaporation from Puddles]

(After showing a picture of puddles)

I. Subject matter knowledge interview

1. What would happen to puddles when the sun comes out after a rain?
2. Where do puddles go when the sun comes out after a rain?
3. What happens to the water when it evaporates? Does it still exist after it evaporates? If yes, in what form it exist? If no, how?
4. Can you ever see water vapor?

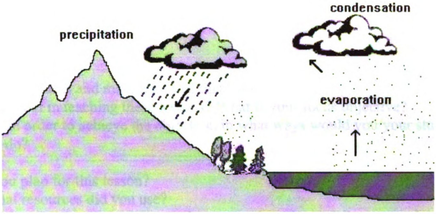
II. Scenario

Imagine that your students answer above question. How would you respond to the students' ideas? What would you tell each of them about their ideas?

a. Jane: A puddle of water outside *can't* evaporate on a cloudy day.
b. Paul: The water disappears when it dries up.
c. Carl: The weight of water is lost when evaporated.
d. Bill: Evaporating puddle makes the air humid.

[Scientific Practice Interview Protocol] – Inquiry and Application

I. (After showing them a diagram of the water cycle)



I would like to ask you to suggest real-world examples happening around your school that you could use to illustrate what is happening at different points in each stage of the water cycle?
How could you help your students to connect the stage with the example?

II. People have different approaches to understanding science content such as *the Water Cycle*.

Imagine that you are teaching *the Water Cycle* in your class. A group of the students are bringing these personal observations into the classroom.

- Frost on the grass
- Fog on a mirror
- Puddles drying up
- Rain falling from dark clouds
- Water on the outside of a cold pop can.

How would you respond to and use these examples? How would you use these observations? To make science learning meaningful, how would you teach and introduce *the Water cycle*? Do you have *any other ideas* to successfully teach *the Water cycle*? What would you do and use, and what would you tell them for a good teaching of *the Water cycle*?

2. Pre-Observation Interview Protocol

This interview is to explore your thinking about the teaching of the next lessons about the Water cycle (condensation, evaporation, precipitation, and overall water cycle). I would like to ask you about what you are thinking about the lesson you are going to teach. This conversation is to share what you are planning to do, and how you are anticipating things will go.

[Planning]

1. What are the big ideas and main points of this topic?
2. What is your goal in teaching these lessons? What is your focus objective?
   Probe: In order to achieve the objective, in what ways would you/your students like to do?

3. How did you plan for this lesson?
   Probe: What resources did you use?
   (Based on the particular curriculum and resource they chose) What particular things appeared in the resource/materials do you think are critically important to include in your teaching? Why?
   What would you do differently from the existing materials? Why?
   How did you decide on particular activities that you are planning to do?
   What made you decide to use them?

4. Is there any particular activity, thing, or example in this lesson you would like to include and emphasize? What are they? Why would you like to have and choose it? How would you like to do it?

5. What would you particularly expect to see happened in the lesson?
Is there any particular problem you would like to solve in this lesson? Why? How?

[Teaching Activity and Strategies]

1. To teach this topic, how would you teach and lead the classroom activity?
Probe: How would you approach to help students understand the content well?

2. Is there any specific thing, skill, strategy or whatever you wish to have for the successful accomplishment and to achieve the focus objectives?
Probe: content knowledge for the topic, management skills, teaching materials, etc.)

3. How would you as a science teacher prepare for the expected students difficulties?

[Assessment of student learning]

1. What would you expect your students to know or be able to do that would show a good understanding of this topic?

2. How would you know if your students get the understanding of the topic you teach?

3. What assessment methods would you use to figure out their learning? Why?

4. For this lesson, what kind of students' (or your) difficulty would you expect in their learning (and your teaching)? Why?

[Self-evaluation about the preparation for the lesson]

1. How do you feel about your teaching of this lesson?

2. Do you feel like you need to know more and have more to teach this lesson well? If so, what are they? And why? If not, what made you feel this way?
Probe: content knowledge for the topic, management skills, teaching materials, etc.)

3. About this lesson, what do you feel confident about? Why?
What do you feel nervous about? Why?

4. What do you feel comfortable with? Why?
What do you feel uncomfortable with? Why?

3. Post-Observation Interview Protocol

After your teaching the past lessons of the Water cycle (condensation, evaporation, precipitation, and overall water cycle), I would like to talk with you to get your reactions to the lessons. I also selected some video clip of a part of your teaching that I was particularly impressed with since I am trying to better understand what you were thinking and doing.

[Reflection of Teaching Practice]

1. What do you think about this lesson?
Probe: How satisfied are you with this lesson?

2. What were your general plans in your mind prior to your teaching of the water cycle?
Probe: Do you think that you achieved your original plans? If yes, what made it possible for you to achieve that? If no, what made it difficult for you to achieve that?

3. What did you particularly expect to see happened in the lessons?
What was the particular problem you wanted to solve in the lessons? Why? How?

4. What was your focus objective?
Probe: In order to achieve the objective, in what ways did you/your students try to do? Do you think that you achieved your original plans? Why?

5. What were particular activities/examples/materials you emphasized in teaching of the water cycle? What were they? Why did you choose it? How did you like to do it?

6. Considering your original planning compared to your actual teaching performance of the water cycle, what changes were made? What caused the changes? Why?

7. What were the most important teaching activities and performance you enacted for teaching of the water cycle well? Why?
Probe: What would be the most important aspects of your teaching to teach the water cycle to your students? Why?

8. [In teaching Condensation/Evaporation/Precipitation/Overall pattern of the water cycle]
What specific key examples do you think were important in your teaching?
What particular patterns do you think were important in your teaching?
What particular scientific explanations and theories you wanted to emphasize for your students?

9. How you think you did with respect to getting the class to do what you wanted? Are there some particular examples that illustrate that?
Probe: What do you think made your teaching going difficult or very well? Why? How?

10. What constitutes your good teaching performance of the water cycle?
Probe: Science knowledge? Classroom management? Understanding of students? Anything else?

11. Was there any specific thing, skill, strategy or whatever you wish to have for the successful accomplishment and to achieve the focus objectives?

12. What do you wish you tried more about? Why?

13. What do you wish you knew more about? Do you see a way that this will happen for you?

14. Do you have ideas about how you might like to do it differently or improve it next year?

[Assessment of Students Learning]

1. What kinds of students' classroom actions do you think would show their good understanding of the water cycle?

2. What kinds of students' classroom actions do you think would show that the lesson objectives/goals were attained?

3. In terms of students' learning, how would you assess the students' learning and understanding? How can you know this student understand the water cycle (condensation, evaporation, condensation)? What would be the particular evidence to support your assessment?

4. (About some of students' work)
What do you think this student understands about the water cycle (condensation, evaporation, precipitation, overall pattern of the water cycle) you are teaching? What evidence about understanding do you see in these examples?
Suppose you had time to do an in-depth interview with a student about this topic? What other questions would you like to ask? What would the ideal answers be?

5. What difficulties do you see in your students as they try to make sense of this topic? What are the biggest barriers to their understanding?

6. What are the important attributes for students' learning?

[Perception about content understanding, students, pedagogy]

1. How do you feel about your content understanding at this point in your career?
Is there more that you need to learn about science content to be the kind of teacher you want? What? Why?

2. How do you feel about your understanding of students at this point in your career?

Is there more that you need to learn about students to be the kind of teacher? What? Why?

3. How do you feel about your teaching strategies at this point in your career?
Is there more that you need to learn about teaching activities and practices to be the kind of teacher? What? Why?

4. Stimulated Recall Interview Protocol based on videotaped teaching

*** As watching some video clips,
I will be particularly looking for below significant classroom events in the teaching events:

- When the teachers tell the important story of the water cycle relevant topics,
- When they address naïve conceptions or incorrect ideas of the water cycle to the class,
- When they show demonstrations and conduct experimentations with the students,
- When they mention/teach the particular content knowledge of the water cycle,
- When they ask questions to the students about the water cycle,
- When they respond to students' questions of some content of the water cycle,
- When they have some conversations/dialogues with the students about the water cycle,
- When they make changes either of some portion of their planned teaching activities, or of the suggested activities from the curriculum materials,
- When they correct students' answers/works,
- When they assess students learning, and
- When they do not take appropriate/immediate actions to students' learning behaviors (e.g. not trying to solve the problems, ignoring the significant events, etc.)

1. It strikes me that you have paid a lot of attention to_____. Does this also strike you as important? How so?

2. In addressing and teaching the content appeared in the video clip, what were you think about the students' actions? Did you have any particular reason why you did that?

3. With respect to these video clips, can you say more about what you were thinking as this was happening?

Probe: What made you decide to do that? How? Why?

Appendix B. Data Analysis by three occasions of data collection: Interviews, teachers' teaching practices, and students' learning activities

A. Data analysis in Interviews

Science Knowledge and Practices (Experiences, patterns, explanations; Inquiry and application)	**Sense-making strategies** (Procedural display, practical reasoning, narrative reasoning, and model-based reasoning)
Data Sources (the interview questions) ** Scientific Explanation* 1. What do you think will happen to the ice inside the cup? Why? 2. How do you think the weight of the water from the ice melting will compare with the weight of the ice? Why? 3. What would happen to the balance as time passes by? 4. What would happen the outside of an iced cup? 5. Where do you think the moisture on the outside of the cup came from? 6. Was it something else before it was liquid water? What? ** Experiences/Patterns* 1. Can you think of other times when something like this happens? 2. What have you noticed when you watch clouds? 3. What are some things that you know about clouds? (Scenario) Let's spend some time considering three students' ideas about this classroom event. How would you respond to the students' ideas? What would you tell them about their ideas? a. Jane: The iced cup is sweating. b. Paul: The water outside of the cup comes from inside of the cup. c. Carl: The water in the air moves to the outside side of the iced cup. d. Mary: Hydrogen and oxygen in the air are water on the cup. e. Joe: Water is evaporating from the water in the cup and condensing on the outside of the cup. ***Data Analysis for Scientific Knowledge*** • Examine how teachers distinguish types of knowledge on condensation. • Examine which extent of their knowledge in each category, experience, patterns, and explanations they come up with on condensation. • Investigate whether they can come up with examples, data, and observations on condensation. • Investigate what kinds of specific examples, data, and	***Data Sources (the interview questions)*** • All of the questions on the left columns on condensation ***Data Analysis for Sense-making strategies*** • Sort the teachers' statements into different categories, and look for qualitative patterns in the lists of their sense-making strategies. • Examine whether they rely on procedural display by repeating factual definitions of the science facts, showing superficial understanding of the condensation, and telling the simple story of condensation. • Examine whether they have practical knowledge by accounting for scientific phenomena of condensation based on their personal experience in non-scientific life. • Examine whether they use narrative reasoning by explaining the scientific phenomena as a form of story that contains the story of the general facts, telling a sequence of event without rigorous causation, and frequently using analogies or metaphors that take a familiar and experientially real form to the teachers. • Examine whether they perform model-based reasoning by developing an account that systematically relates observed characteristics of the scientific phenomena to a theoretical model. • While the teachers respond to the scenario that includes students' possible ideas and concepts, Examine the types of their scientific reasoning when correcting the students' ideas, suggesting ways to teach the students for scientific understanding.

observations on condensation they can come up with. • Investigate whether they can find scientific patterns in examples, data, and observations on condensation. • Investigate what kinds of specific patterns in examples, data, and observations on condensation they can find. • Examine whether they can come up with scientific explanations on condensation. • Examine what kinds of specific scientific explanation they can come up with. • With above scenario, look for their thoughts and ideas of the particular examples of students' conceptions of evaporation and their ways of responding to students' various knowledge/ideas on condensation. ***Data Analysis for Scientific Practice*** • Examine whether they can make connections among the various science knowledge through scientific practice: inquiry and application on condensation. • Look for teacher's ways of engaging in scientific Inquiry. • Examine whether the teachers can use the scientific examples and observations to find patterns and develop scientific explanations. • Look for teacher's ways of engaging in scientific application. • Examine whether they can use the scientific explanations, and heories to explain the real world examples (model based reasoning)	

B. Data analysis in videotaped Teachers' Teaching Practices

Science Knowledge and Practices (Experiences, patterns, explanations; Inquiry and application)	**Sense-making strategies** (Procedural display, practical reasoning, narrative/metaphorical reasoning, and model-based reasoning)
Data Sources (Videotaped teaching event) • When teachers conduct the condensation activity, Investigation 3, Clouds and the Sun (BSCS students edition, Lesson 6 – What drives the weather?: pp 74-75) and review the activity with students, • When teachers address/explain the idea of condensation in their classroom teaching practice, • When they lead discussion about the activity and findings from the investigations on condensation. • When the class reads BSCS book (page 78) about the water cycle and discuss the vocabulary, particularly the word condensation. • When the teachers discuss with the students about Clouds Facts (student page pp 79-80) and read about the role of the Sun.	***Data Sources (Videotaped teaching event)*** • All of the data listed on the left columns ***Data Analysis for Sense-making strategies*** • Sort the teachers' teaching behaviors and statements into different categories, and look for qualitative patterns in the lists of their sense-making strategies. • Examine whether they rely on procedural display by repeating factual definitions of the science facts, showing superficial understanding of the condensation, and

• When they review cloud formation and different types of clouds (pp 81-83), • When the students review and discuss about Water as three different states as solid, liquid, and gas. ***Data Analysis for Scientific Knowledge*** • Examine how teachers distinguish types of knowledge on condensation. • Examine which extent of their knowledge in each category, experience, patterns, and explanations they come up with on condensation. • Investigate whether they can come up with examples, data, and observations on condensation. • Investigate what kinds of specific examples, data, and observations on condensation they can come up with. • Investigate whether they can find scientific patterns in examples, data, and observations on condensation. • Investigate what kinds of specific patterns in examples, data, and observations on condensation they can find. • Examine whether they can come up with scientific explanations on condensation. • Examine what kinds of specific scientific explanation they can come up with. • With above scenario, Look for their thoughts and ideas of the particular examples of students' conceptions of evaporation and their ways of responding to students' various knowledge/ideas on condensation. ***Data Analysis for Scientific Practice*** • Examine whether they can attempt to make connections among the various science knowledge through scientific practice: inquiry and application on condensation and cloud formation. • Look for teacher's ways of engaging students in scientific Inquiry. • Examine whether the teachers can use the scientific examples and observations to help students find patterns and develop scientific explanations. • Look for teacher's ways of engaging students in scientific application. • Examine whether they can use the scientific explanations, theories, and models to help students explain the real world examples through model-based reasoning.	telling the simple story of condensation. • Examine whether they have practical knowledge by accounting for scientific phenomena of condensation based on their personal experience in non-scientific life . • Examine whether they use narrative reasoning by explaining the scientific phenomena as a form of story that contains the story of the general facts, telling a sequence of event without rigorous causation, and frequently using analogies or metaphors that take a familiar and experientially real form to the teachers. • Examine whether they perform model-based reasoning by developing an account that systematically relates observed characteristics of the scientific phenomena to a theoretical model. • While the teachers engage in the classroom discourse with students and respond to students' questions and learning behaviors that includes students' possible ideas and concepts, Examine the types of their scientific reasoning when correcting the students' ideas, suggesting ways to teach the students for scientific understanding.

C. Data analysis in videotaped Students' Learning Activities

Science Knowledge and Practices	**Sense-making strategies**
(Experiences, patterns, explanations; Inquiry	(Procedural display, practical

and application)	reasoning, narrative/metaphorical reasoning, and model-based reasoning)
Data Sources (Videotaped learning event) • When students conduct the condensation activity, Investigation 3, Clouds and the Sun (BSCS students edition, Lesson 6 – What drives the weather?: pp 74-75) and review the activity with their teacher, • When they present/address/explain their ideas of condensation in their classroom learning practice, • When they are lead to discussion about the activity and findings from the investigations on condensation. • When the class reads BSCS book (page 78) about the water cycle and discuss the vocabulary, particularly the word condensation. • When the class discuss with the teacher about Clouds Facts (student page pp 79-80) and read about the role of the Sun. • When they review cloud formation and different types of clouds (pp 81-83), • When the students review and discuss about Water as three different states as solid, liquid, and gas. ***Data Analysis for Scientific Knowledge*** • Examine how students distinguish types of knowledge on condensation and cloud formation. • Examine which extent of their knowledge in each category, experience, patterns, and explanations they come up with on condensation. • Investigate whether they can come up with examples, data, and observations on condensation. • Investigate what kinds of specific examples, data, and observations on condensation they can come up with. • Investigate whether they can find scientific patterns in examples, data, and observations on condensation. • Investigate what kinds of specific patterns in examples, data, and observations on condensation they can find. • Examine whether they can come up with scientific explanations on condensation. • Examine what kinds of specific scientific explanation they can come up with. • Examine how the students respond and react to teacher's questions and engage in classroom discourses with their teacher in large and small group discussions, and various classroom events about condensation. • Look for their naïve ideas on condensation and cloud formation. ***Data Analysis for Scientific Practices*** • Examine whether students can attempt to make connections among the various science knowledge through scientific practice: inquiry and application on condensation and cloud formation.	***Data Sources (Videotaped learning event)*** • All of the data listed on the left columns ***Data Analysis for Sense-making strategies*** • Sort the students' classroom behaviors and statements into different categories, and look for qualitative patterns in the lists of their sense-making strategies. • Examine whether they rely on procedural display by repeating factual definitions of the science facts, showing superficial understanding of the condensation, and telling the simple story of condensation. • Examine whether they have practical knowledge by accounting for scientific phenomena of condensation based on their personal experience in non-scientific life. • Examine whether they use narrative reasoning by explaining the scientific phenomena as a form of story that contains the story of the general facts, telling a sequence of event without rigorous causation, and frequently using analogies or metaphors that take a familiar and experientially real form to the teachers. • Examine whether they perform model-based reasoning by developing an account that systematically relates observed characteristics of the scientific phenomena to a theoretical model. • While the students engage in the classroom discourse with their teacher, Examine the types of their scientific reasoning when they respond to the teacher's correction of their ideas and suggestions to follow directions of classroom learning.

•Look for students' ways of engaging in scientific Inquiry. •Examine whether the students can use the scientific examples and observations to help students find patterns and develop scientific explanations. •Look for students' ways of engaging scientific application. •Examine whether they can use the scientific explanations, theories, and models to help students explain the real world examples through model-based reasoning.	

Appendix C. Analysis of Teacher and Students' Activities suggested in BSCS Textbook

Lesson Sequence	Activities	Role of 5E Model	Expected Teacher Activities (Suggested Teacher Feedbacks, Actions)	Expected Students Activities (Activity questions, goal activities)
Lesson 1	[Part1] List the weather words and think about whether those words are related to the Sun.	Engage	Teachers were recommended to • Ask the students which words they think have something to do with energy from the Sun. • Draw or ask a student to draw a "sun" beside those words. • Accept all ideas at this time to move the discussion along. • If there is disagreement, place a question mark by the word. Tell students they will revisit the chart at the end of the lesson and can address the words with questions marks then.	Students were expected to • Come up with any of their ideas that could possibly connect to the weather. • The BSCS anticipated that by the end of the lesson, the students attain "more complete ideas," ideas at the beginning of the class. • Key Questions o What is weather? o Make a list with your class of things that you think make up the weather. o How many of the weather words on the list have something to do with the Sun?
Lesson 1	[Part 2] Provide students with prior experience and a set of common experiences about evaporation and condensation. (Investigation 1: Boiling water in a saucepan, Investigation 2: Observing water in 4 shallow dishes, Investigation 3: Observing the outside of the iced cup.)	Explore	Teachers were recommended to • Review with students On Your Own activity, Clouds and the Sun, in the student guide. • Ask students to describe the three different investigations they will perform at home using simple kitchen equipment. • Inform students when their results are due. • Instruct students to be ready to share their observations, questions, and records from their journals. • (By assigning three parts of activities) to assure of a set of common experiences upon which students can base further discussion. • If teachers do not think that many students will be able to do the investigations at home, then set up the investigations in the classroom, but expect students to complete their observations and records "independently."	• Students were expected to complete the three investigations to make and record observations "independently." • Key Questions o How does the water get into the air? o What is responsible for getting it there. o Do some investigations at home and see what you can find out. • Investigation 1: Evaporation o What do you think happened to the water? o What caused the water to change? • Investigation 2: Evaporation o What happened to the water? o Why aren't all the saucers empty? o What caused the water to change? o Do you think the other saucers

			• Understand that without common experiences, some students might not have enough prior experience with evaporation or condensation to make sense of the reading and discussion about clouds that follow.	eventually will become empty, too? Why or why not? • Investigation 3: Condensation o Did your cup leak? o Where did the water on the outside of the cup come from? o What is the temperature of the outside of the cup compared to the temperature of the air in your kitchen? o Where else have you seen water droplets on cold surface? (Did you see water droplets on the plastic wrap in Investigation 2?) o Does this investigation have anything to do with clouds? Explain what you think.
Lesson 2	Review what students experienced with the three investigations they performed.	Explain	Teachers were advised to • Ask students to share with the class their observations from the investigations they performed at home • Rather than getting reports from many students, ask one student to report and then ask if anyone has anything different to report or anything to add. • Take time to discuss the events in Ideas to Think about and the questions embedded within the investigations. • Ask students to explain what these investigations have to do with the Sun and with clouds. • Probe their thinking by asking guiding questions and allow students to disagree with one another. • Not expect all students to agree and do not take time now to come to any consensus. This	The students were expected to • Report to the class what they observed from the investigations. • Have a chance to think about questions of 5 real world examples, which were mostly related to evaporation. (There were no any examples given for condensation, though.) • Explain what happens to the water and how the energy was involved in the process of evaporation. • Expect to have the disagreement rather than trying to gain consensus – c.f. BSCS envisions that students will reach the consensus throughout the lessons and the development of students' scientific thinking will be promoted through their questioning of their own reasoning and their results in

			is the time to get all ideas "out on the table" so that students can question their reasoning and possibly their results. They will discuss these ideas throughout the lesson.	investigations. • Key Questions • Read about the following events. Think about what is happening relative to the water. Explain what you think happened to the water. Describe the energy that was involved. – Dried wet towel, mopping the floor, blowing wet hair with the dryer, wet shirt in the dryer, and dried puddle.
Lesson 3	Read the informational reading about three stages of water cycle and discuss the vocabulary, particularly evaporation and condensation	Explain Elaborate	Teachers were asked to • Together with the students, read Water: Solid, Liquid, and Gas. • Discuss the vocabulary, particularly the words, evaporate and condense. • Help students connect the reading to their investigations at home when they observed evaporation and condensation. • Refer to the questions in Ideas to Think about. • Brainstorm other situations when students have seen evaporation and condensation. • Include some of the following in everyday observations of evaporation and condensation: Fog, Dew, Foggy mirror in the bathroom after a shower, Foggy windows in the car when the car is full of people, Foggy goggles when skiing, Humidifiers and dehumidifiers. • For each of the examples, discuss where the energy comes from that evaporates the water. • Discuss what provides the cool surface for condensation. • Continue the reading with The Role of the Sun. • Help students connect the energy from the Sun to the energy needed to evaporate water. • In addition, help students see that the cool surfaces needed for condensation also are	Students were expected to • Read about the water cycle, the informational text -- Water: Solid, Liquid, and Gas. • Understand the particular concepts, such as evaporation and condensation. • Relate those ideas to their real world situations that might be drawn from the three investigations they did. • Continue the reading with The Role of the Sun and Clouds Facts. • Key Questions o When do you think you were observing evaporation? o When were you observing condensation? o What is weather? o What does water have to do with weather? o What does the Sun have to do with the weather? o What do you think drives the weather? o Can you figure out what each of these combination clouds might look like?

			dependent on energy from the Sun. • Review the water cycle – draw on chart paper or on the blackboard a diagram similar to the one in the student guide; help students understand the movement of water through the land, oceans, and atmosphere; remind them that water evaporates from Earth's surface, both from water on land and water in the oceans. • Ask students for their questions; Model the team skill, ask questions to help you understand someone else's ideas. • Spend some time making sure that the students understand the abstract concept of the water cycle. Ask questions similar to these to determine if they are ready to move on. • Continue by reading, Clouds Facts • Read the introduction to the activity, Winds and the Sun.	

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