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BONDING IDEAS ABOUT INQUIRY: EXPLORING KNOWLEDGE AND PRACTICES OF METACOGNITION IN BEGINNING SECONDARY SCIENCE TEACHERS

by

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A DISSERTATION

Presented to the Faculty of
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Metacognition, identified generally as “thinking about thinking,” plays a fundamental role in science education. It enhances the understanding of science as a way to generate new knowledge using scientific concepts and practices. Moreover, metacognition supports the development of students’ life-long problem solving, collaboration, and critical thinking skills. When teachers use metacognition with intention, it can promote students’ agency and responsibility for their own learning. However, despite all of its benefits, metacognition is rarely seen in secondary science classrooms. Thus, it is important to understand what beginning teachers know and how they use metacognition during their first years in order to find ways to prepare and support them in incorporating metacognitive practices into their science teaching.

The purpose of this multimethod study was to describe the metacognitive knowledge and experiences of beginning science teachers. For the quantitative research strand, I surveyed 36 secondary science teachers about their awareness of metacognition and used classroom observations coded from a larger research study to identify how often teachers were using metacognition to teach science. For the qualitative strand, I interviewed 15 participants about their knowledge and experiences of metacognition.
(including reflective practices) and spent two weeks observing two of the teachers who described exemplary metacognitive teaching practices.

I found that participants had a solid awareness of metacognition, but considered the term complicated to enact, difficult for students, and less important to focus on during their first years of teaching than other elements such as content. Additionally, teaching experience seemed to have an effect on teachers’ knowledge and experiences of metacognition. However, participants who were using metacognitive practices had recognized their importance since the beginning of their teaching. Reflective practices can help improve teaching, but what seems more effective is for teachers to have an experience using metacognition embedded in science content.

The results of this study include a description of metacognitive teaching practices that could be helpful for secondary science teachers. The study also provides recommendations for future research, especially for teacher education programs, to promote a better understanding of metacognition while preparing secondary science teachers.
This dissertation is dedicated to:

God, for giving me this opportunity and the strength to accomplish it.

My parents, Eric and Mari Carmen Rivero, for their example, support, and love.

My sisters, Araceli, Pamy, Maruch, and Mech, for always encouraging me.

To all my family and friends, and especially those who I met in Lincoln during my graduate studies. I have you all in my heart.

To those heroic science teachers who do their best every day in their classrooms to promote students’ scientific literacy.
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To my professors, especially to Dr. Loukia Sarroub for helping me discover the perspective of an educational researcher.

To the science teachers who generously agreed to participate in this research study, with my admiration, affection, and respect.

To my research group, Aaron Musson, Jia Lu, Lyrica Lucas, and Amy Tankersley, for sharing this wonderful research adventure with me; and to all the people who contributed somehow to this project.
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CHAPTER 1: INTRODUCTION

Metacognition and Science Teaching and Learning

“Teaching is a necessary creative act” (Edwards & Thomas, 2010, p. 412). In science education, teachers’ creativity is a necessary condition to promote scientific literacy in secondary students. That is, science teachers in the 21st century require creativity to recognize and utilize science in the context of students’ (and their own) life situations, including ethical, political, social, or economic considerations, in order to support the development of students’ citizenship and make science accessible for all (Roberts & Bybee, 2014). Science teachers need creativity to understand how contexts interact with scientific concepts and practices to develop students’ higher-order thinking and problem-solving skills needed for future challenges.

Especially for beginning teachers, developing creativity will be key during their first years, considering that they will promote scientific literacy perhaps for the first time in a specific context. Early-career teachers will need creativity to experiment and take risks to learn how to relate science to students as individual learners (Mycroft & Gurton, 2011), and part of a community. Therefore, science teaching should involve actions that enhance and elicit both students’ and teachers’ creativity and thinking. Thus, as Dewey (1910) stated, teaching should involve “alertness, flexibility, and curiosity,” all elements linked with creativity, rather than “routine, dogmatism, or prejudice” (p. 105), elements related with a more traditional understanding of teaching. Science classrooms must be places where creative thinking is modeled and promoted.

Creativity also relies on the development of higher-order skills, making it an important element in teaching science. In the United States, the Next Generation Science
Standards (NGSS) promote a high-quality science education in which “students will develop an in-depth understanding of content and develop key skills—communication, collaboration, inquiry, problem solving, and flexibility—that will serve them throughout their educational and professional lives” (NGSS Lead States, 2013, para. 4). All of these skills are complex in nature, requiring the development of a net of knowledge and abilities. For example, inquiry involves a group of different scientific and engineering practices (Appendix A) such as asking questions, organizing and analyzing information, providing scientific argumentation, or presenting results (Osborne, 2014). Teachers require creativity to connect those skills to students’ lives and interests while promoting a deep understanding of science. Therefore, teachers need to be creative in order to adapt science curriculum to students’ different needs and contexts and promote learning.

Fortunately, we have more knowledge about learning now than in the past (Wilson & Conyers, 2013), and this knowledge can help teachers promote real and in-depth learning experiences. For example, theories of conceptual change explain how learners’ prior knowledge and experiences can be transformed into new learning, helping them make sense of new information (Duit & Treagust, 2003; Pintrich, Marx, & Boyle, 1993; Posner, Strike, Hewson, & Gertzog, 1982). Researchers have explained that learning is about meaning-making (Meltzer & Hamann, 2004). Therefore, when teachers explore students’ experiences and ideas about a topic before instruction, they can find strategies to support learning more effectively. Learning theories may also provide teachers with clues about how they can promote students’ complex skills. In order to understand these clues, new teachers must incorporate reflection about their experiences in the classroom and connect that reflection with learning theories. Reflective practice
can thus improve teaching and learning in the classroom (Belvis, Pineda, Armengol, & Moreno, 2013). Reflection about learning theories and experiences can also support teachers in developing a more critical view of their teaching and what happens in the classroom, leading to improved practice.

Furthermore, we live in a world where change is an important element. We know that knowledge continually changes, and even science evolves as a consequence of human activity (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). In this changing world, teachers and students should learn how to build new connections themselves. Effective teachers must become long-life learners capable of adapting to new situations, while students should understand how to learn independently if they want to extend their science learning outside of school. Moreover, students in secondary science classrooms need to learn how to identify their own voice and opinions about what they observe, be able to assess the validity of new information, and have confidence in their arguments and judgments (Howitt & Wilson, 2014). These are skills that will help them become critical thinkers and solve future challenges.

Therefore, science education must focus on teaching students how to gain self-confidence in order to become not just independent thinkers but also lifelong learners (Howitt & Wilson, 2014). In other words, one of the goals of science education should be to develop students who are motivated to learn throughout their entire lives, confident in their own judgements, and open to change. In order to achieve these goals, science teachers must model the process of lifelong learning and demonstrate how science can contribute to students’ lives.
The Role of Metacognition in Learning Science

Metacognition has been widely studied in education and other fields (e.g., psychology). Researchers have found evidence of the fundamental role of metacognition in several of the goals of science education, including the search for creativity, scientific and engineering practices, scientific concepts, meaning-making, and the development of lifelong learning (e.g., Holton & Clarke, 2006; Mycroft & Gurton, 2011; Thomas & Anderson, 2014). John Flavell, who is considered the father of this field, came up with the term in the 1970s based upon Piaget’s ideas of cognitive development.

Metacognition is a complex and multifaceted concept that entails several types of knowledge, self-regulation, control, and affective experiences that interact with personal epistemological beliefs (Barzilai & Zohar, 2014). Thus, it is a construct that involves and overlaps with other terms (e.g., reflection, self-regulation, scaffolding) (Dinsmore, Alexander, & Loughlin, 2008; Holton & Clarke, 2006). Metacognition involves thinking about learning, cognition about cognition, “thoughts about thoughts, knowledge about knowledge, or reflections about actions” (Papleontiou-louca, 2003, p. 10). Throughout educational research, its most common definition is thinking about thinking.

Moreover, metacognition is connected to the development of higher-order thinking skills, such as critical thinking, collaboration, problem-solving, and a deep understanding of the epistemology of science (Ben-David & Orion, 2012; Zohar & Barzilai, 2013). In science education, it plays a key role in teaching and learning science through inquiry (Seraphin & Philippoff, 2012). Metacognition helps learners develop an awareness of their needs and increases their knowledge of their goals, strategies, and selves. Additionally, a connection exists between metacognition and formative
assessment (Heritage, 2014), by which teachers and students can elicit their thinking to inform and improve teaching and learning.

As a former science teacher and teacher educator, I find metacognition is fundamental in the process of conceptual change and an important element in the science classroom. It helps learners become aware of how they make connections between prior knowledge, experiences, misconceptions, and new knowledge and skills. For teachers, especially during their first years, using metacognition can help them develop, monitor, and evaluate goals and strategies to improve their practice, gain self-confidence, and become more effective as they acquire experience. Metacognition also involves the awareness of learning in order to improve practice, which for students might include the development of scientific skills, a deep understanding of concepts and science, and confidence about their judgements. For new teachers, metacognition can be part of their reflective practices about how to effectively develop students’ complex skills, such as science and engineering practices and scientific concepts. Furthermore, students require metacognition when they engage the so-called three dimensions of the NGSS: science and engineering practices, crosscutting concepts, and multidisciplinary ideas. These three dimensions should occur in a context where students develop a deep understanding of science while they make meaning and connections with their lives and interests, recognizing how they learn. Metacognition can thus build important bonds: between the learner and their goals, prior and new ideas, plans and strategies, personal skills and scientific practices, school and real life, and experience and scientific concepts.

Researchers have found many compelling reasons to use metacognition in the science classroom. When embedded in science instruction, metacognition contributes to
learning in inquiry-based activities, collaborative work, and real-problem settings, especially among low-achievement students (White & Frederiksen, 1998; Kramarski, Mevarech, & Arami, 2002). Studies in metacognition have revealed the importance of helping learners increase and monitor their thoughts and actions in order to gain better control over them (Schwartz, Scott, & Holzberger, 2013). Metacognition may also have a positive impact in dealing with problems of transfer and the durability of science concepts (Georghiades, 2000). Moreover, researchers have found a significant correlation between metacognitive awareness (or knowledge) and life satisfaction in adolescents (Cikrikci & Odaci, 2016). Once learners understand their own learning, they can transfer these skills to any domain or situation (Schraw, 1989). Wilson and Conyers (2013) thus refer to metacognition as a gift that lasts a life time.

However, metacognition requires explicit instruction and intention through classroom activities and discourse (Thomas & Anderson, 2014; Wilson & Conyers, 2013). That is, science teachers need to include explicit metacognitive strategies and experiences as part of activities embedded in their regular inquiry lessons (Pintrich, 2002). After conducting a longitudinal study of Swiss students between tenth and twelfth grade, Leutwyler (2009) concluded that high school students generally do not develop metacognitive knowledge or skills independently. Instead, teachers should model metacognitive thinking so that students can see it in action (White, Frederiksen, & Collins, 2009). They can do this by embedding metacognition in their science curriculum and emphasizing the importance of becoming a lifelong learner through intention and explicit instruction.
Moreover, as part reflective practice, secondary science teachers should plan, monitor, and assess their pedagogical strategies in order to improve their instruction. Teachers’ reflection can be used as an opportunity to improve processes of inquiry, including the metacognitive practices it requires (White, Frederiksen, & Collins, 2009). It is essential for teachers both to design metacognitive practices for students and to develop their own metacognitive thoughts. Especially during their first years of teaching, when everything is new for them, teachers need to engage in high levels of metacognition (Duffy, Miller, Parsons, & Meloth, 2009). Yet more work is still needed to understand and support beginning teachers in this learning process (Russell & Martin, 2014). The present study aims to add to this understanding.

**Metacognition and the Gap Between Theory and Practice**

While researchers in science education recognize metacognition's role in science learning, there is a gap between theory and practice. Unfortunately, knowledge and practices of metacognition are not commonly found in science classrooms (Ben-David & Orion, 2012; Duffy et al., 2014). For example, college chemistry students in one study reported a lack of metacognitive learning strategies and had difficulties assessing how thoroughly they had learned the material (Zhao, Wardeska, MacGuire & Cook, 2014). In light of this research, secondary science education must contribute to the development of metacognitive learning strategies and prepare students not only with knowledge, but also with the skills needed to succeed in higher educational levels.

Duffy et al. (2009) called for empirical evidence of teachers’ metacognition in order to understand their processes of learning to teach science. Perhaps with a better understanding of this process, teacher education programs and administrators can find
ways to support and encourage teachers to use metacognition in their classrooms. Additionally, Russell and Martin (2014) stated that additional work must be done to acquire a better understanding of the relationship between new teachers’ experience and learning. Metacognition clearly plays an important role in this relationship.

With several of these considerations in mind, from 2012 and 2016 I participated in a four-year longitudinal study of four cohorts of secondary science teachers who graduated with Master’s degrees in education from a Midwestern state university. The research group analyzed and coded 319 science lessons from new teachers (ranging from student teaching to their third year of independent teaching) to describe their enacted practices. We used the Electronic Quality of Inquiry Protocol or EQUIP, a standardized research instrument, developed to assess inquiry-based science lessons (Marshall, Horton, Smart, & Llewellyn, 2008). Student reflection was one of the least observed assessment factors in our study (Table 1.1). We found instances of student reflection in only 6% (on average) of observed lessons.

Student reflection could also be considered an indicator of explicit metacognitive instruction or metacognitive teaching practices because of the deep relationship between these two constructs. After this study, we acknowledged the possibility that student reflection and metacognition presented a real challenge for teachers in the induction phase, as participants did not often appear to use these strategies in the lessons we observed (Lewis, Rivero, Musson, Lu, & Lucas, 2016). Even though reflection and metacognition are essential elements for science learning, it was difficult to find metacognitive teaching strategies in regular instruction. This observation was the starting point of the present research project. I wanted to describe what secondary beginning
teachers know about metacognition and how they use it on two different levels: in their own reflective practices for improvement, and in their classrooms to promote the three NGSS dimensions, especially using scientific and engineering practices.

Table 1.1

*Effective Aspects of Assessment: Percentage of Observed Science Lessons at “Proficient” or “Exemplary” Levels of Inquiry* (n=319) (Lewis et al., 2016)

| Assessment Factors | ST** % (n=71) | Year 1 % (n=116) | Year 2 % (n=95) | Year 3 % (n=37) | Mean % (with ST) | Mean % (Induction ***)
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<tbody>
<tr>
<td>A1: Prior Knowledge</td>
<td>1</td>
<td>3</td>
<td>9</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>A2: Conceptual Development</td>
<td>24</td>
<td>18</td>
<td>43</td>
<td>53</td>
<td>34</td>
<td>38</td>
</tr>
<tr>
<td>A3: Student Reflection</td>
<td>6</td>
<td>3</td>
<td>15</td>
<td>0</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>A4: Assessment Type</td>
<td>24</td>
<td>15</td>
<td>32</td>
<td>45</td>
<td>29</td>
<td>31</td>
</tr>
<tr>
<td>A5: Role of Assessing</td>
<td>3</td>
<td>6</td>
<td>13</td>
<td>16</td>
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<td>12</td>
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*“Proficient” scored a 3 and “Exemplary” scored a 4 on the EQUIP instrument.
**ST: student teaching ***Induction: Year 1 to 3

Exploring teachers’ knowledge and understanding of metacognitive teaching practices can provide some hints as to why they may not be using these practices for science instruction. Research has found that teachers' knowledge and experiences can influence their teaching styles and the types of instructional practices they use (Maggioni & Parkinson, 2008; Powell, 1996). However, there are very few studies of secondary science teachers’ knowledge of metacognition (Zohar & Barzilai, 2013). More data is needed to understand to what extent teachers practice metacognition, the factors or
models influencing this practice, and the effect of metacognitive practices on students’ achievement (Duffy et al., 2009; Maggioni & Parkinson, 2008). This study focused primarily on the first category, teachers’ knowledge and practices or experiences of metacognition, rather than on student achievements.

Therefore, this study sought to generate a better understanding of what beginning secondary science teachers know and the practices they use as elements of the creative act of teaching. Moreover, studies in metacognition are especially important for high-needs schools serving at-risk populations of students. As mentioned previously, metacognition can help struggling students become more responsible for their learning.

Additionally, there is a call for teacher education programs to create environments that prepare reflective practitioners (Parker & Heywood, 2013), which can in turn promote improved teaching practices and lifelong learning. Scholars consider reflection an indispensable skill for teachers, especially during their first years (Marzano, Boogren, Heflebower, Kanold-McIntyre, & Pickering, 2012; McGregor, 2011). Understanding reflective practices and metacognitive knowledge in beginning science teachers can support not only teacher education programs (TEPs) but also school administrators in designing strategies and contexts that promote metacognitive experiences and improve teaching and learning. Furthermore, descriptions of metacognitive teaching practices can provide secondary science teachers with ideas about how to use them in their own classrooms.

**Purpose of the Study**

The purpose of this multimethod study was to describe the metacognitive knowledge and practices of beginning science teachers (0 to 5 years of experience) after
completing a teacher education program. I collected qualitative and quantitative data simultaneously, analyzed each strand separately, and then merged them for analysis. For this study I used the *Metacognitive Awareness Inventory for Teachers* (MAIT) (Balcikanli, 2011) to understand new teachers’ awareness of metacognitive knowledge and skills in quantitative terms. I also used data from a larger study on the evaluation of two science teacher education programs. The qualitative data (open-ended interviews, classroom observations, and artifact analysis) described participants’ knowledge of and experiences with metacognition based on their teaching practices and level of reflection. The rationale for collecting both quantitative and qualitative data was to acquire a better understanding of teachers’ metacognitive knowledge and experiences. The two forms of data offered a greater insight into the issue than would be obtained by either type of data separately.

The proposed research questions for this study were:

1. What is beginning secondary science teachers’ understanding of metacognition?

   Specifically,

   a. To what extent are these teachers aware, or unaware, of their knowledge of metacognition?

   b. What is participants’ knowledge of metacognition as an element for science teaching?

2. What common instructional practices (metacognitive teaching) related to metacognition do beginning science teachers use?

   a. What elements do teachers believe can affect their instructional practices of metacognition (or metacognitive teaching) as part of science instruction?
3. What are teachers’ practices or experiences of metacognition (i.e., reflective practice)?
   
a. What factors affect teachers’ experience of metacognition?

4. What knowledge and experience of metacognition affect teachers’ instructional practices of metacognition (or metacognitive teaching)?

Exploring teachers’ awareness of metacognition provides insight into their understanding and use of this construct as part of their teaching, inside and outside the science classroom. My hypothesis was that teachers who have an increased knowledge or awareness of metacognition are more likely to develop metacognitive teaching practices. I also hypothesized that teachers’ level of experience and reflective practice might influence their knowledge and practices of metacognition.

I describe the study in detail in the following four chapters. In Chapter 2, the literature review, I explain the concept of metacognition, its origins, and a model for understanding its components. Additionally, I explore its relationship to concepts such as reflection, formative assessment, collaboration, and the epistemology of science. I then outline research-based metacognitive teaching practices in the science classroom and studies about metacognition and reflective practices in science education.

Chapter 3 details the theoretical framework for this study, which is drawn from conceptual change theory, along with my approach as a researcher. I describe in detail the research design, including quantitative and qualitative stands, study participants, instruments used, and how I analyzed the information for trustworthiness. The quantitative strand included a survey and coded information from observations of a larger research study. The qualitative strand included 15 open-ended interviews and classroom observations of two teachers using exemplary metacognitive teaching practices.
I describe the study findings in Chapter 4, using the research questions as an organizational structure. I begin by describing teachers’ awareness of metacognition after a statistical analysis of the MAIT survey. I additionally use qualitative data to describe their understanding of the term metacognition. Next, I generate a diagram to represent metacognitive teaching practices. I then analyze reflective practices in the participants to explore possible connections to their metacognitive teaching practices. Finally, I describe a lesson and artifacts used for assessment by two teachers utilizing metacognitive practices for science instruction. The chapter ends with a list of the hypotheses or study claims generated with the evidence collected and analyzed.

Chapter 5 provides a discussion of the study’s findings, limitations, and conclusions. I again draw on the four main research questions to organize the research-based claims, illustrate the evidence gathered in this study, and compare it with other research studies and theories about metacognition in the current literature. I propose a model to illustrate my findings as a conclusion of the study.

Finally, Chapter 6 describes the limitations and relevance of the study. I include recommendations for future research and for teacher education programs based on my findings. The chapter ends with the conclusions of this research project.
CHAPTER TWO: LITERATURE REVIEW

There is a consensus in science education that inquiry-based instruction should play a fundamental role in building students’ scientific literacy. However, there are still science teachers who believe in the effectiveness of direct instruction. Moving away from a teacher-centered, fact-giving model of science education to a more student-centered one requires a shift in teachers’ beliefs and knowledge. That is, science teachers must view their lessons as opportunities to become models of thinking and designers of students’ discoveries through their own inquiries (Siegel, 2012). Modeling is essential in developing learners’ metacognitive knowledge and skills.

*Teaching science as inquiry* is a pedagogy that engages students in designing and carrying out investigations using what the Next Generation Science Standards (NGSS) define as scientific and engineering practices, together with crosscutting concepts and disciplinary core ideas (NGSS Lead States, 2013). This happens when students learn how science generates new knowledge (Osborne, 2014). Thus, learning science involves more than just learning scientific theories or skills. It requires the coordination of the learner’s complex set of cognitive, affective, and motivational strategies (Anderman, Sinatra, & Gray, 2012). Facilitating science learning also means equipping students with critical thinking, problem solving abilities, complex communication skills (i.e., oral and written), and interpersonal skills and adaptability (i.e., to others’ ideas or new situations) in order to face the challenges of the twenty-first century (Anderman et al., 2012; Wilson & Conyers, 2013). In all of these processes, metacognition plays a fundamental role.

Therefore, for this chapter, I will first define metacognition and its relationship with other, similar terms. Next, I provide a theoretical model for knowledge and practices
of metacognition, based on Flavell’s (1979) research. Then, I explain the relationships between metacognition and the epistemology of science and among metacognition, collaboration, and formative assessment. I next describe metacognitive teaching practices in the science classroom and teachers’ reflection as experiences of metacognition. Finally, I present prior research about metacognition and reflective practices in science education.

**Metacognition**

Metacognition is a construct studied and discussed extensively because of its important role in learning. The National Academy of Science (NAS) (2001) called it a crucial skill for effective thinking and problem-solving. Metacognition is related to Dewey’s ideas in the early 20th century about reflection and thinking (Tanner, 2012; Silver 2013). However, several authors have contributed to the development of metacognition as a theoretical framework, including Jean Piaget’s theories of human development and Vygosky’s research on the importance of social interactions in learning. Most importantly, John Flavell is considered the father of metacognition for inventing the term. Metacognition is associated with higher thinking skills and the ownership of one’s own learning (Wilson & Conyers, 2013), and is considered an integral operator in learning and thought (Schwartz et al., 2013). Therefore, metacognition is a fundamental element for science education and the development of scientific skills and knowledge.

Dewey (1910) defined thinking as “that operation in which present facts suggest other facts (or truths) in such a way as to induce belief in the latter upon the ground or warrant of the former” (p. 8). To think means to use prior ideas to form new ones and trust them as correct. Moreover, Dewey introduced the idea of reflective thought in
educational settings as the “active, persistent, and careful consideration of any belief or supposed form of knowledge in light of the grounds that support it, and the further conclusions to which it tends” (p. 6). Dewey used the concept of inquiry to explain the relationship between experience, experimentation, and thinking in the development of those conclusions. In his book *How We Think* (1910), Dewey suggested five steps for reflective thinking: (1) a felt difficulty or an anomaly; (2) its location and definition; (3) the suggestion of a possible solution (i.e., hypothesis) or variety of alternative suggestions; (4) development by reasoning of the implications or consequences of the solution; and (5) further observation and experimentation to accept or reject the hypothesis tested. The outcome of this process could be a conclusion of belief or disbelief. This process is still generally accepted in school settings as promoting reflection in the classroom and is considered a milestone for metacognitive teaching practices (McGregor, 2011; Silver, 2013).

However, Dewey’s reflective thinking model has also been criticized for its overreliance on technical rationality (i.e., knowledge is understood exclusively as coming from the intellect and can be attained through a systematic process and rational analysis); its attachment to a problem or a problematic situation as a starting point; its support of practical or experiential knowledge; and its lack of space for values, routines, or norms (Hébert, 2015). In this study, Dewey’s process is still relevant and explains how science education and the use of inquiry and scientific practices can develop scientific thinking. The process also relates to conceptual change theories of science learning, mainly because both start with a problem and require action and experience to develop new learning.
Definition of Metacognition

Metacognition, or the awareness of thinking (Zimmerman, 2002), is traditionally defined as thinking about thinking. Wilson and Conveys (2013) explained the concept as “thinking about one’s thinking with the goal of enhancing learning” (p. 110). Therefore, metacognition should play an important role in educational settings. Students must learn about various content, but they must also learn collaboration, problem-solving, reading, writing, and other complex learning tasks that will require metacognitive awareness (Frith, 2012; Holton and Clarke, 2006; Wilson & Conyers, 2013). Schools should prepare students to understand their own thinking processes while they work together, solve problems, use numbers and scientific models to represent ideas, communicate findings, and enhance their higher-order thinking skills.

In the most fundamental research on this subject, Flavell defined metacognition as “knowledge and cognition about cognitive phenomena” (Flavell, 1979, p. 906). Cognition is how the learner encodes, memorizes, and recalls information after interaction with real objects, ideas, and abstractions in the experiential world (Holton & Clarke, 2006; Schraw, Crippen, & Hartley, 2006). The NAS (2010) defines cognition as the “theory or set of beliefs about how students represent knowledge and develop competence in a subject domain” (p. 44). Thus, metacognition is how the learner’s mind mediates, controls, and monitors cognitive processes (Flavell, 1979; Frith, 2012; Holton & Clarke, 2006). Metacognition depends on the knowledge of cognition and involves the monitoring and regulation or control of this knowledge (Silver, 2013).

Schraw (1989) recognized metacognition as the monitoring of cognition, further differentiating it from knowledge of cognition. Additionally, Schraw (1989) described the
monitoring of cognition or metacognition as planning, monitoring, and evaluating. Planning involves setting up goals, establishing the appropriate strategy, and allocating resources to conduct the strategy. Monitoring indicates the ability to self-test a learning task performance periodically. Finally, evaluation relates to the assessment or judgment of goals, products, and strategies. For Schraw, metacognition was not required to accomplish a cognitive task. On the other hand, Lemons, Reynolds, Curtin-Soyodan, and Bissell (2013) affirmed that higher-order thinking skills (e.g., application, analysis, synthesis, and evaluation) do require metacognition to perform. In any case, being aware of their own cognition can improve students’ learning (Schraw, 1989; Wilson & Conyers). Wilson and Conyers (2013) defined learning as a process of gathering information, exploring and elaborating on that information (i.e., defining problems, making inferences, comparing, classifying, making connections, planning and organizing, memorizing, and summarizing), and communicating it (i.e., considering others’ viewpoints, expressing ideas effectively, etc.). Within this definition, learning involves several cognitive processes and thinking skills. Metacognition thus means to become mindful of these processes and consciously recognize when and how to employ them as problem-solving strategies.

In short, metacognition not only encompasses knowledge or awareness of thinking, but also involves the planning, monitoring/control, and evaluation of thinking skills. Moreover, Silver (2013) explained that the capacity for forming goals, planning, organizing, monitoring, and evaluating is called the executive function of the brain. Metacognition helps to develop the prefrontal cortex of the brain where the executive functions take place.
**Model of Metacognition**

John Flavell (1979) proposed the first model for metacognition (Figure 2.1). He defined the concept using “four classes of phenomena” (p. 909), which all interact with each other: (1) cognitive actions or strategies; (2) cognitive goals or tasks; (3) metacognitive knowledge; and (4) metacognitive experiences.

![Model of Metacognition](image)

*Figure 2.1. Flavell’s model of metacognition, using Zohar and Barzilai’s (2013) terms. Knowledge of metacognition interacts with cognitive actions and goals to develop experiences of metacognition, and vice versa.*

A cognitive goal could be what Dewey (1910) termed “the problem,” such as something that produces discomfort, a discrepant event, or a felt need. Silver (2013) described a cognitive goal as similar to a learning task. Flavell (1979) defined “problem” as “the objectives of a cognitive enterprise” (p. 907). For example, in the classroom a problem could be related to learning purposes or goals or to something the learner wants to achieve. These goals must then be transformed into actions, by which learners look for the appropriate strategy to achieve the goal or complete the task. Flavell (1979) described cognitive actions as behaviors employed to achieve the goal. The learner will use her prior knowledge of metacognition to complete these tasks, drawing on an awareness of
what she already possesses in a toolbox of thinking skills. Then, she uses those skills as strategies to achieve her goals, creating experiences of metacognition that will increase her knowledge of metacognition.

For this study, knowledge of metacognition consists of the knowledge, beliefs, and ideas that the learner has previously stored related to the tasks, goals, context, norms, skills, and regulation (Flavell, 1979; Zohar & Barzilai, 2013). When a person turns knowledge of metacognition into actions in a real activity, it is transformed into an experience of metacognition (Zohar & Barzilai, 2013). Flavell (1979) explained that experiences of metacognition “are any conscious cognitive (i.e., ideas) or affective (i.e., feelings) experiences that accompany and pertain to any intellectual enterprise” (p. 906), including decisions and actions (Flavell, 1979). Experiences of metacognition usually are complex activities that require a thinking process and knowledge.

For example, experiences of metacognition could occur while teaching science as inquiry. Scientific and engineering practices might be considered complex problem-solving activities, especially when they include open-ended inquiry. Students provided with a concrete problem must choose strategies to accomplish their goal. Moreover, the problem needs to be complex enough to represent a challenge for students, since “metacognition has been related with problem solving where problems are not usually of any standard type” (Holton & Clarke, 2006, p. 132). Students need to participate in the decision-making process, and highly-regulated lab practices do not sufficiently provide these opportunities. Teachers who promote students’ scientific practices will already have experiences with metacognition that help them understand how to facilitate these moments effectively and accomplish their learning goals.
Therefore, using scientific practices could be considered an experience of metacognition for both teachers and students: for teachers, because they will learn how to effectively make decisions based on students’ inquiries and learning processes; and for students, because they must come up with their own decisions and actions about how to solve their problems during the inquiry process. In both cases, metacognition can play an active role and can help to mediate and enhance learning.

*Figure 2.2. Metacognitive knowledge embedded in teaching science as inquiry. Metacognition relates to learning (i.e., psychological metacognition) and to how scientific knowledge is generated and validated (i.e., epistemological metacognition).*  

Knowledge and experiences of metacognition are active processes and are interconnected. An experience of metacognition will increase future knowledge of metacognition, while knowledge of metacognition will inform experiences of metacognition and its tasks, therefore improving and increasing metacognition overall (Schraw, 1989). Knowledge helps develop teaching strategies that can be transformed into experiences, which will then inform and increase future knowledge. When teachers
think or reflect about enacted practices, those thoughts can help them in their own learning process.

Knowledge of metacognition has three main components: (1) metacognitive knowledge (MK), (2) metacognitive skills (MS), and (3) metacognitive experience (ME) (Flavell, 1979; Schraw, 1989; Zohar & Barzilai, 2013). These components relate to the traditional classification of knowledge as declarative, procedural, and conditional (Figure 2.2) (Ritcher & Schmid, 2010). Metacognitive knowledge (or declarative knowledge of metacognition) includes memory and beliefs about knowing (Ritchner & Schmid, 2010; Schraw & Moshman, 1995) as well as a knowledge of cognitive strategies (Pintrich, 2002). The use of these strategies, on the other hand, would be considered experiences or practices of metacognition. Metacognitive knowledge also indicates what someone knows about an action, goal, or strategy, as well as one’s self-knowledge and beliefs about performing that action. Finally, metacognitive knowledge includes knowledge about persons, tasks, and strategies. Zohar and Barzilai (2013) explained:

Knowledge of persons refers to self-knowledge of the variables that influence the individual’s cognitive activity, knowledge of the cognition of others and knowledge of the universals of people’s cognition. Knowledge of tasks refers to understanding how the nature of tasks’ conditions, demands and goals affects cognitive activity. Knowledge of strategies refers to knowledge about thinking, learning and problem-solving strategies that students might use in order to achieve goals. (p. 123)

Metacognitive skills (MS) or procedural knowledge of metacognition include the monitoring and self-regulation of a cognitive activity or goal (e.g., making predictions,
organizing data, planning an experiment), as well as the knowledge of planning, monitoring, and evaluating a complex assignment (Zohar & Barzilai, 2013). Metacognitive skills are connected to procedural knowledge (Schraw & Moshman, 1995) and impact a person’s performance of a sequence of steps or procedures that has been planned in advance.

Metacognitive experiences (ME), or the conditional knowledge of metacognition, are connected to the affective dimension of learning. Zohar and Barzilai (2013) described metacognitive experiences as those “aha moments” learners find when they have a deep understanding of a concept or discover a connection that makes sense. Metacognitive experiences are also associated with conditional knowledge (Schraw & Moshman, 1995), the knowledge of when and how to use a cognitive action or specific strategy to solve a problem. For example, metacognitive experiences might help a teacher know whether to answer a student’s question or remain silent, or whether to intervene or step aside while students are working. As another example, a major educational movement supports the importance of learning after making non-harmful mistakes, arguing that teachers should learn how and when to use this pedagogy to enhance students’ learning. This conditional knowledge also helps teachers to know what guidance, instructions, or information students require before, during, or after an inquiry activity or while using a scientific practice. Metacognitive experiences, then, include the learners’ discoveries about themselves and their knowledge of when to apply new learning.

Declarative, procedural, and conditional knowledge of metacognition all inform the decisions and cognitive actions of a learner. For instance, while beginning teachers acquire some knowledge during their teacher education programs, they will continue
developing knowledge as they gain experience. For early-career teachers, conditional knowledge can be critical, since it involves knowing how and when to use a strategy based on students’ context and needs. Experiences will increase teachers’ understanding of the knowledge learned after TEPs and will provide them with additional knowledge about teaching strategies and how to use them.

**Metacognition and other constructs**

Metacognition can potentially be seen as a complex construct or a multidimensional phenomenon (Schraw, 1989). It includes several other constructs, such as planning, self-regulation, and evaluation, as well as different sorts of knowledge and experiences interacting. Therefore, metacognition has been considered a vague or fuzzy term and is often transposed or confused with similar terms, such as reflection, self-regulation, self-regulated learning, and reflective thinking. Metacognition is sometimes used as a synonym for these terms, sometimes like an overarching construct, and sometimes as part of a larger process.

For example, metacognition and self-regulation are constructs that are related. Metacognition includes planning and monitoring of cognitive processes, which are processes linked to self-regulation, while self-regulation includes thinking about thoughts and learning. Moreover, there is a significant research movement based on both terms. For instance, self-regulation and learning studies are based on Albert Bandura’s legacy (instead of Piaget’s theories, for example). Zimmerman (2002) defined self-regulation as “what students needed to know about themselves in order to manage their limitations during efforts to learn” (Zimmerman, 2002, p. 65). To accomplish this, Zimmerman (2002) noted that students require metacognitive skills. Metacognition and self-regulation
are thus connected; however, no consensus exists about how this connection works. Sometimes researchers use the two terms interchangeably, sometimes hierarchically (Barzilai & Zohar, 2014; Dinsmore et al., 2008). That is, some authors use them as synonyms, while some argue that metacognition requires self-regulation or that self-regulation requires metacognition.

For the purposes of this study, metacognition and self-regulation are interrelated terms, but not synonyms (Appendix B) (Dinsmore et al., 2008), as there are important practical and philosophical differences between them. Throughout this study, I will consider self-regulation as an important aspect of metacognition, included as part of the planning, monitoring, and evaluating of cognitive processes.

Furthermore, metacognition and reflection are two terms with unclear boundaries. Educators frequently use the term reflection to describe metacognitive practices (Silver, 2013). Metacognition has also been defined as reflecting about thinking (Duffy et al., 2009). Silver (2013) explained that there are differences and similarities between these two terms. Reflection is a conscious exploration of one’s experiences in accordance with Dewey’s definition of reflective thought. Therefore, reflection can be understood as thinking about actions, while metacognition can be understood as thinking about one’s own thought process. However, thinking about actions could also be included in metacognition, as in Favell’s model (Figure 2.1). Moreover, Dewey (1910) considered reflection as a regulator of thinking, which is related to the concept of metacognition. McGregor (2013) related reflection and reflective practices with improvement, while Schraw (1998) explained evaluation (for improvement) as part of metacognitive processes.
Silver (2013) explained that in a technical sense, reflection and metacognition are different. That is, similar to the relationship between self-regulation and metacognition, researchers have developed relatively independent studies about reflection and reflective practices. For example, Donald Schön is considered the originator of the idea of the reflective practitioner in the 1980s. Since his work, several studies have been conducted about reflection and professional expertise (e.g., Collin, Karsenti, & Komis, 2012; Hébert 2015, Malthouse, Roffey-Barentsen, & Watts, 2014). Nonetheless, research in metacognition supports the importance of reflective practices (Marzano et al., 2012), and reflection can be part of a moment or stage in some metacognitive models (Silver, 2013). Additionally, research finds that teachers prefer to use the term “reflection” with students when they promote student metacognition (Silver, 2013; Zohar & Barzilai, 2013). Therefore, I will use reflection and metacognition interchangeably in this study, especially when I describe how teachers use metacognition in the science classroom and enact reflective practices that function as metacognitive experiences for improving their professional expertise.

Other terms for metacognition include scaffolding (Holton & Clarke, 2006), self-regulated learning (Dinsmore et al., 2008), and “reflective thinking” or “self-monitoring” (Moallem, 1997). Veenman, Van Hout-Wolters, and Afflerback (2006) listed several terms used in the literature related to metacognition:

- Metacognitive beliefs
- Metacognitive awareness
- Metacognitive experiences
- Metacognitive knowledge
- Feeling of knowing
- Judgment of learning
- Theory of mind
- Metamemory
- Metacognitive skills
- Executive skills
- Higher-order skills
- Metacomponents
- Comprehension monitoring
- Learning strategies
- Heuristic
strategies, and self-regulation are several of the terms we commonly associate with metacognition. (p. 4)

Finally, I decided to use the term metacognition for this study over other terms (e.g., self-regulation, reflective practice) because it serves as an overarching concept. For example, it encompasses self-regulation and reflection. Additionally, metacognition is part of the conceptual change framework and includes an epistemological stage that relates to the nature of science, as I will describe later (Amin, Smith, & Wiser, 2014). I believe it is ultimately a more inclusive and complete term. While metacognition may be complex and difficult to define or understand, this complexity can also provide a “theoretical umbrella” for referring to certain aspects of teaching and learning (Duffy, et al, 2009).

In science education, learning must be related to the processes of thinking behind scientific theories and practices. Science is not just about conducting experiments or learning concepts with no connection to real life. It should also involve a deep understanding of its epistemology—that is, science as a way to generate new knowledge and solve problems. Therefore, metacognition can help facilitate the teaching and learning of science. Moreover, it can encourage students to become aware of their thinking processes and to mirror the behaviors of professional scientists (Seraphin & Philippoff, 2012); that is, to know what, when, and where to think like scientists. If thinking skills are related to scientific practices (such as identifying a problem, gathering information, planning an experiment, making predictions, communicating findings, analyzing or summarizing data and evidence, or coming up with conclusions) then metacognition is the understanding of what, how, and where to use those tools.
Therefore, scientific practices are tools for developing new scientific knowledge and skills, while metacognition helps the learner to plan, control, and evaluate how and where use them.

**Metacognition as a skill**

As research has shown, knowledge and experiences of metacognition should be embedded in regular science lessons (Adler, Zion, & Mevarech, 2015; Postholm, 2011; Lovett, 2013; Wilson & Conyers, 2013). In other words, science teachers should include metacognitive strategies in their lesson plans and enact them, reflecting on and explaining their function and relationship to learning in the classroom (Pintrich, 2002).

Metacognition can be enacted as reflection in order to enhance students’ learning strategies, understanding of science, attitudes toward science, and achievements (Zohar & Barzilai, 2013). To this end, teachers should create spaces where students can reflect on their learning in inquiry lessons or through the use of scientific practices. Teachers should also be aware of their own learning and thinking processes in order to adapt their teaching to students’ needs.

Knowledge and experiences of metacognition have been shown to help students learn more effectively, as they seem related to the transferability of learning (Lovett, 2013; Pintrich, 2002; Schraw, 1989; Silver, 2013; Wilson & Conyers, 2013) as well as to student empowerment and independent learning (Wilson & Conyers, 2013; Zimmerman, 2002). The use of different metacognitive experiences in science classrooms will help teachers cultivate independent and long-life learners, as students will learn how to understand their thinking processes when they deal with a complex or unknown situation.
Metacognitive skills are like any other skill: they require practice (Lovett, 2013). This practice can help learners transfer these skills across disciplines and contexts (Lovett, 2013; Wilson & Conyers, 2013). Schraw (1989) explained that while cognitive skills are specific for each content area, metacognition “spans to multiple domains, even when those domains have little in common” (p. 116). Wilson and Conyers (2013) called metacognition “a gift that lasts a lifetime” (p. 19). That is, experiences of metacognition can help to increase a learner’s knowledge of metacognition. With enough practice and understanding, the learner will be able to use this knowledge in any situation, both inside and outside of school.

If learners understand how they learn, and thus how they can use metacognition to plan, monitor, and evaluate their learning, they will be more likely to be empowered, responsible, and in control (Wilson & Conyers, 2013), contributing to their development as independent and lifelong learners (Holton & Clarke, 2006). Teachers and students should thus learn how to transfer their experiences onto other situations. Thinking about their thinking can help them understand how they make decisions, react under certain circumstances, and accept responsibility for their actions.

Metacognition can also be a powerful tool for making disenfranchised students more aware of their learning process, as learners who are aware of and responsible for their own processes will also possess a greater sense of agency and empowerment. This empowerment is especially fundamental for students in underrepresented groups or those with lower achievements in science. For these students, developing metacognition can mean the difference between spending time in school and actually learning science (Howitt & Wilson, 2014).
While the benefits of a metacognitive teaching approach are widely recognized, some teachers might not teach metacognitive practices because they assume students will not understand how to perform them. Adults tend to be more aware of their own cognition than children and adolescents (Schraw & Moshman, 1995), so not every teacher understands the need to explicitly teach metacognitive strategies as part of a science curriculum. Yet research shows that metacognition does not develop spontaneously in all students. As a result, teachers must help learners understand how they gain knowledge, set goals for further improvement, and check their ongoing progress with purpose (Bixler, 2011). I provide more detailed recommendations for teaching metacognition later in this study. In the following section, I describe the important relationship between metacognition and the epistemology of science.

Nevertheless, metacognition is not solely about cognition, learning processes and thinking skills. It also includes an epistemological component. In science education, metacognition is also connected to how the field of science generates new knowledge (i.e., the epistemology of science).

**Metacognition and Epistemology of Science**

In the context of a lesson, metacognition can have two dimensions: the psychological and the epistemological (Richtner & Schmidt, 2010) (Figure 2.2). The psychological dimension of metacognition is better known and most commonly referenced. As described in the previous section, based on Flavell and other scholars’ work, this dimension comprises the knowledge, skills, and experiences of cognitive processes related to learning. Additionally, however, metacognition can also regulate the
cognitive processes related to generating new knowledge, referred to as epistemic metacognition.

Epistemology means a theory of knowledge, the ways in which we come to know something (Espinoza, 2012). Epistemic metacognition denotes the knowledge, skills, and experiences regarding the nature, accuracy, and validity of knowledge and the strategies and processes used to gain it (Barzilai & Zohar, 2014; Richter & Schmidt, 2010). For example, metacognitive knowledge in the “traditional sense” refers to the psychological mechanisms underlying memory and learning (psychological metacognition). In contrast, epistemic metacognition refers to “the nature of knowledge and the criteria that beliefs and assertions must fulfill to be considered as valid or reliable knowledge” (Richtner & Schmidt, 2010, p. 48). This includes knowledge and beliefs about, for example, the nature of truth; what counts as a valid argument; to what extent an experimental design is reliable; or the accuracy of measurements gathered (Richter & Schmidt, 2010). When students think about these issues, they are using epistemic metacognition.

Epistemic metacognition works when teachers and students reflect on what counts as valid knowledge or implement knowledge-based validation and consistency checking. Knowledge-based validation is an assessment of the type of learning materials or information based on what students know already about the topic; consistency checking involves an analysis of the consistency of information and whether it is well-justified and well-used (Richter & Schmid, 2010). For example, epistemic metacognition answers questions such as: How do I know the data are valid? Is this evidence enough to support my claims? Are these arguments strong enough to support a conclusion? How do you know this is true? Knowledge-based validation and consistency checking require
students’ higher thinking skills and reflection and, therefore, metacognition. When students practice and reflect on the validity of their arguments and thoughts, they can develop tools and strategies to support their judgements and gain greater confidence in their abilities.

Amin et al. (2014) explained that an epistemological understanding of science has been an important tool for developing scientific literacy in science education. Osborne (2014) wrote that using epistemic knowledge with scientific and engineering practices helps students to understand, for example, whether data gathered after an experiment are valid or reliable and why this is important in the context of the experiment. Therefore, practicing and using epistemic metacognition in the science classroom is important for developing critical thinking, which requires higher-order thinking skills (Lemons et al., 2013). Epistemic metacognition will help learners understand how and why scientific knowledge was generated and develop expertise using scientific and engineering practices.

Consequently, epistemic metacognition is also associated with the nature of science (NOS) (Osborne, 2014; Peters & Kitsantas, 2010; White et al., 2009), which encompasses the philosophical dimension of science or the essence of scientific knowledge. This notion explains how scientific knowledge can be valid, reliable, and understood as truth. The NOS derives from the epistemology of science, which is “science as a way of knowing, or the values and beliefs of scientific knowledge and its development” (Lederman, Antink, & Bartos, 2012, p. 331). This refers to how scientific knowledge is generated and the assumptions attached to it, as well as how this knowledge is obtained, checked, and refined (Osborne, 2007). The nature of science serves as a
source for scientists, teachers, students, and citizens to pose questions and find answers; use scientific practices to generate evidence; solve problems; and generate new knowledge.

Ledermann (2007) and Abd-El-Khalick, Waters, and Le (2008) provided a list of general parameters offered by the NOS as a frame of reference. Osborne (2014) summarized the work of these studies in the following NOS features: (1) science is empirically based; (2) scientific knowledge is imaginative and creative; (3) it is based on inferences (i.e., explanations beyond the senses); (4) scientific knowledge is dominated by theoretical and disciplinary commitments (e.g., influenced by scientists’ prior knowledge, beliefs, expectations, and paradigms); (5) it is subject to change (although reliable as the best explanation available); (6) socially negotiated (within a scientific community); and (7) culturally embedded; (8) there is a distinction between a scientific law (based on observations) and theories (based on inferences); and (9) there is no singular “scientific method.” Although Osborne (2014) acknowledged that science is more complex than what can be represented in the former list, it nevertheless provides a general idea of what science is and how it works to generate new knowledge.

Bartos and Lederman (2014) concluded that secondary teachers must have strong beliefs and intentions about how the NOS benefits students in order to embed it in their science content effectively. According to this research, having clear assessment strategies in order to allocate the same importance to the NOS and course content was an indicator of these beliefs. Additionally, the authors found that teachers must possess a strong knowledge of their subject matter.
In sum, questions about knowledge-based validation and validity checking, along with reflections on how science generates new knowledge (i.e., the nature of science), are an important aspect of epistemic metacognition. Including epistemic metacognition in the science classroom can help students develop critical thinking skills, as they will acquire the habit of questioning why and how the information they collect is important, true, and valid.

Science generates and validates new knowledge as a social construction (Longino, 1990). As part of the nature of science, collaboration among the scientific community plays an fundamental role in validating knowledge. Thus, the social element of science must also be emphasized in the secondary science classroom throughout the teaching of science as inquiry and its relationship to metacognition. I elaborate further on the importance of prioritizing collaboration in the following section.

**Metacognition and Collaboration**

It is a common conception to relate thinking and reflection with a process of individual introspection, internalization, and self-awareness. Therefore, metacognition could potentially be understood as the result of individual learning after a teaching strategy (Porayska-Pomsta, 2016). Nevertheless, metacognition is not only a self-reflective activity, but is also a social process (Adler et al., 2015; Thomas & McRobbie, 2013; Porayska-Pomsta, 2016; Papeontiou-louca, 2003). Social and cultural components mediate and enhance metacognitive knowledge and practices (Azevedo, 2005, Frith, 2012; Porayska-Pomsta, 2016; Thomas & McRobbie, 2013).

Metacognition is the awareness of learning. Since learning is inherently social, according to Vygotsky’s theories (Papeontiou-louca, 2003), metacognition must include
a social component in order to strengthen the awareness of learning. Experiences and theories can additionally inform how the learner make sense of knowledge. Moreover, science is a social construct. Kuhn (2012/1962) explained how theories become part of a paradigm through the collaborative, social nature of a scientific community. Therefore, a social component not only enhances metacognitive processes but is also part of the nature of science. This does not mean that metacognition cannot occur through self-reflection or self-evaluation. However, interactions with others can help learners expand their understanding of a phenomenon or an activity in order to develop new knowledge.

Edward and Thomas (2010) described knowledge as “to be actively coping in the world of meaningful experience organized through social forms of activity” (p. 408). If metacognition is related to knowledge and learning, then collaboration and social interactions can enhance metacognition. In other words, metacognitive awareness or knowledge grows when students interact with their teachers and peers as part of an experience of metacognition (Papleontiou-louca, 2003). Metacognition will also help students regulate their group work and learn how to collaborate and make decisions while considering others’ views and opinions.

Therefore, an effective metacognitive process for learning should include a social component. For example, in inquiry activities using scientific practices, students and teachers could be involved explicitly in a reflective process in which they review their working processes and products (White & Frederiksen, 1998). This process needs to be explicit, in that the teacher must facilitate it with intention and highlight these moments of collaborative reflection and evaluation. Using Bartos and Lederman’s (2014)
conception of importance in class, teachers should consider these shared reflections, analysis, and evaluation as part of the formal evaluation of the activity.

Sharing different perspectives, listening to others’ points of view, using diverse sets of values and sociocultural backgrounds for planning activities, and assessing goals can all enhance metacognition in the classroom (Azevedo, 2005; Porayska-Pomsta, 2016). Paying attention to what others are thinking and doing based on their positions can contribute to understanding one’s own positions, values, and principles. Metacognition can thus mediate the understanding of one’s self through understanding and respect for others as part of a community of learners.

Moreover, engaging in collaborative reflection can encourage students to think about how they might improve their processes (Azevedo, 2005; White et al., 2009). This benefit connects to Vygotsky’s zone of proximal development, as learners might have a better understanding of how to reflect on their thinking by observing and interacting with other learners or their teachers. Therefore, teachers should design collaborative situations to use more frequently in the assessment and development of metacognition (Azevedo, 2005). However, if learners struggle to work together, the experience of metacognition might not be as effective as planned. Facilitators of experiences of metacognition (e.g., teachers and administrators) thus need to be aware of and support learners in collaborative situations.

Some teachers might assume that their students already know how to collaborate, but this is not always the case. Students require instruction about how to organize and regulate group activities and how to learn through a collaborative process of inquiry (Saab, van Joolingen, & van Hout-Wolters, 2012). In order to enhance knowledge and
experiences of metacognition, teachers need to explicitly include collaboration as part of the experience and provide support for making group work effective (Wilson & Conyers, 2013). In sum, metacognition requires explicit instruction, including an explanation of how collaboration can enhance the learning process. In the following section, I describe how metacognition should be embedded into science instruction.

**Metacognitive Teaching Practices**

Schraw (1989) explained that metacognition is a skill that can be taught and potentially improved. Similarly, the NAS (2001) affirmed that metacognition develops through years of teaching strategies during a student’s school career. As a complex set of skills, it requires explicit instruction and practice (Joseph, 2009; Lovett, 2013). Moreover, through explicit instruction, modeling, and encouragement, teachers can help students learn how to use metacognition for learning both inside and outside of school (Wilson & Conyers, 2013). There is a general agreement among researchers that metacognition is considered a transferable skill (Schraw, 1989; Lovett, 2013), as it is not content-specific. However, the NAS (2001) advises that it is best accomplished in specific content areas and domains.

Furthermore, Georghiades (2000) explained that instruction in metacognition increased students’ transferability and durability of scientific knowledge. This research found that students could remember science information and course content for longer periods after practicing metacognition in the classroom. When students and teachers learn how to transfer knowledge gathered after complex experiences, they are learning to be flexible and ready to adapt to changing circumstances (Frith, 2012). This adaptation can contribute to their process of becoming independent learners. As a result, metacognition
can be a valuable skill for preparing students to become scientifically literate, lifelong, independent learners who use metacognition not only in the science classroom, but also in their daily lives.

However, learners need support and practice in order to improve their knowledge and practices of metacognition. Teachers can support them through explicit strategies embedded in their instruction and assessment practices designed to actively engage students in metacognitive experiences that support their learning (Lemons et al., 2013; Lovett, 2013; Wilson & Conyers, 2013). In Table 1.1, I present a list of metacognitive teaching practices that scholars and researchers have recommended as strategies for using metacognition in the science classroom.

Moreover, Lovett (2013) and Marzano et al. (2012) suggested steps for teaching metacognition and reflective practices. I synthesize them in the following categories: (1) set up clear learning goals and assessment criteria; (2) provide multiple opportunities for students to practice a skill and track students’ progress (e.g., using formative assessment strategies); (3) use the skill in different contexts and activities to help students learn to transfer; (4) use it the content of the discipline; and (5) celebrate students’ success. Teachers may use the strategies listed in Table 1.1 as part of this process to teach metacognition and reflective practices.

Expertise in metacognitive skills may come after practice embedded in classroom science content. Students require clear goals so that they can follow them and track their performance. When learners practice metacognition in different tasks, they learn how to employ it in different circumstances and improve their transferability of knowledge. Finally, as with any skill, teachers must celebrate successes and accomplishments in
order to motivate students and encourage them to keep working diligently even after setbacks.

Science teachers might assume that students already know how to understand their own thinking and learning when they utilize a scientific practice. This may be true for some, but not for all. In consequence, metacognition should be embedded in the inquiry process (White et al., 2009; Veenman et al., 2006). There are different strategies for using metacognition as part of scientific and engineering practices. In fact, all the scientific practices listed in the NGSS require a complex process of thinking skills that includes metacognitive practices.

For example, in Practice #2, “Using and developing models,” the NGSS included students’ evaluation and refinement of a model after several iterations (NGSS Lead States, 2013). Improving a model and its evaluation requires metacognition. Additionally, students must be able to identify the features of the natural phenomenon that the model represents and its limitations, so that the model can be used to explain, understand, or make predictions about the phenomenon. Models always focus on certain features and leave others aside based on the purpose of the model. Therefore, students should be also able to identify the limitations of the model in an assessment of its purpose and functionality.

Practice #4, “Analyzing and interpreting data,” describes the importance of data validity checking, assessing the methods students used to collect data, and finding possible sources of errors using measurements, all practices aided by metacognition. In Practice #1, “Asking questions and defining a problem,” metacognition intervenes when students learn how to limit or generate more specific questions, considering all the
Table 2.1

Research Recommendations for Instruction of Metacognition in the Science Classroom

GENERAL
- Embed metacognition instruction in the content matter, explain its importance, and practice it (White et al., 2009; Veenman et al., 2006).
- Add metacognitive prompts and questions into instruction (Adler et al., 2015).
- Use reflection or debriefing techniques (Wilson & Bai, 2010): for example, identifying “what you know,” “what you don’t know,” difficulties (Papleontiou-louca, 2003), the muddiest point in a lesson, or confusions (Tanner, 2012).
- Incorporate “think aloud” activities and explanations (Papleontiou-louca, 2003; Wilson & Bai, 2010).
- Paraphrase and elaborate on students’ ideas (e.g., asking them to clarify thoughts, “what you are saying is…”) (Papleontiou-louca, 2003).
- Give realistic advice and encouragement (Joseph, 2009).
- Ask students to plan, monitor, organize and reflect on their work (White et al., 2009; Papleontiou-louca, 2003).
- Facilitate reciprocal-teaching activities (Joseph, 2009).
- Model and discuss scientific and metacognitive thinking so students can see it in action (Papleontiou-louca, 2003; White et al., 2009; Joseph, 2009; Tanner, 2012).
- Label students’ behaviors (e.g., “what you are doing is called an experiment”) (Papleontiou-louca, 2003).
- Create concept maps and relational diagrams (Gunstone & Northfield, 1994).

CLASSROOM ENVIRONMENT
- Integrate a classroom culture of identifying confusion and reflection (Tanner, 2012).
- Create interactive multimedia learning environments (Papleontiou-louca, 2003).

COLLABORATION AND GROUP WORK
- Organize small and whole group discussions about the learning process or an explicit strategy of instruction (Wilson & Bai, 2010).
- Moderate collective reflection and student planning or collaborative work on research projects (White et al., 2009; Bixler, 2011).

SCIENTIFIC PRACTICES
- Use strategies such as “predict-observe-explain” (Gunstone & Northfield, 1994).
- Reflect on making predictions and analyzing evidence (Bixler, 2011).
- Participate in problem-solving and research activities (Joseph, 2009; Papleontiou-louca, 2003).
- Use reflective journals or science notebooks (Gunstone & Northfield, 1994; Papleontiou-louca, 2003; Tanner, 2012; White et al., 2009).

ASSESSMENT
- Set and pursue goals (Papleontiou-louca, 2003).
- Explore the consequences of choices and decisions (Papleontiou-louca, 2003).
- Incorporate self-assessment (Bixler, 2011; Joseph, 2009) and peer assessment (White et al., 2009).
- Reflect on pre- and post-assessments (Tanner, 2012).
- Include reflections in the grading system (Tanner, 2012).
- Incorporate test wrappers (formats to assess how students prepared for a test and help them set up strategies for the next) (Lovett, 2013).
elements that could affect the problem. In Practice #3, “Planning and carrying out investigations,” students should be able to come up with a plan (i.e., set goals), monitor their progress, and evaluate their process and outcomes, in addition to validity checks on their data and methods and the identification of their own biases. In Practice #7, “Engaging in an Argument from Evidence,” students should consider and compare competing ideas and evaluate their methods. In this way, students will have metacognitive experiences using scientific practices that will enhance their metacognitive knowledge as well as their understanding and transference of these practices.

Researchers in science education recommend teaching metacognition with intention while teaching science as inquiry. Practices of metacognition embedded during instruction, such as those listed in Table 1.1, can support science learning (White et al., 2009). However, research finds that teachers do not always have the necessary familiarity with metacognition and need access to metacognitive knowledge and strategies (Veenman et al., 2006). Additionally, because it requires practice, teachers must be willing to invest time and effort in the instruction of metacognition.

In sum, metacognition is present and necessary every time students identify the goals or features of a scientific model or simulation, plan to verify a hypothesis, monitor their progress during an investigation, understand the process of development for a theory, and evaluate their use of scientific practices. Teachers should learn how to facilitate these moments explicitly, repetitively, and with intention, embedding them in the course content. This will help students learn how to use metacognition when they acquire scientific knowledge, as well as allow them to transfer this skill and use it in daily situations. In this way, students will learn to reflect on their processes, a skill necessary
for becoming lifelong and independent learners. Thinking about thinking to enhance learning also relates to formative assessment strategies, as metacognition has an important role in formative assessment. I explain this relationship in the following section.

**Metacognition and Formative Assessment**

Formative assessment and metacognition have a deep relationship (Heritage, 2013). Formative assessment, or assessment for learning, is related to the integration of assessment and instruction through information and adequate feedback (i.e., feedback that is sufficient, pertinent, and timely). Formative assessment is important for both teachers and students. For students, it provides an implicit or explicit plan for future action; for teachers, it allows them to diagnose, monitor, and adapt their instruction (Wiliam, 2007; Bell & Cowie, 2001). Formative assessment is part of the dialogue, discourse, and interactions that occur during teaching and learning.

Formative assessment is a topic largely studied over the past 40 years. Studies have evolved from measuring “waiting time” during teachers’ questioning (Rowe, 1974) to more complex analyses of classroom environment, discourse, students’ and teachers’ roles, empowerment, and metacognition. Authors have found four key elements for formative assessment in the science classroom: (a) a classroom culture that encourages interaction and student involvement; (b) setting learning goals, tracking students’ progress, and using multiple methods of assessment; (c) discourse and other instructional methods that elicit students’ thinking; (d) and feedback on students’ performance and metacognition. In all these key elements, metacognition plays an important role.
As the first key element, formative assessment requires a classroom culture that encourages reflection and interaction (Trauth-Nare & Buck, 2011). Therefore, teachers and students should have a different view of their relationship and the role of assessment than they do in traditional classrooms. For example, in formative assessment, effective student-teacher relationships require more than teachers simply responding to students’ conceptions; they require a shift in classroom roles. This means students should be thinking and actively engaged in their learning, which involves metacognition. Formative assessment also requires teachers to design activities, create learning environments, and provide feedback based on the criteria established at the beginning of the process. Essentially, authority inside the classroom must be shared among teacher and students, and students should become more aware and responsible of their own learning. This is not always an easy process for either of the parties involved.

Teachers must change their beliefs about how a science classroom looks and works and have enough knowledge in order to incorporate formative assessment. They require both sufficient content knowledge (CK) and pedagogical content knowledge (PCK) to feel comfortable sharing control with students and promoting learning based on interactions and questioning (Haug & Ødegaard, 2015; Furtak & Ruiz-Primo, 2008; Nilsson, 2013; Sabel, Forbes, & Zangori, 2015). Teachers’ need for adequate CK and PKC is a recurrent topic in formative assessment research. Furthermore, students must change their beliefs and expectations as well. Buck and Trauth-Nare (2009) found in their study that students’ resistance to formative assessment was due to naïve notions about assessment and/or mistrust of assessment processes. Teachers must thus cultivate a trusting, reciprocal, and egalitarian relationship with students to develop dialogues and
routines that promote formative assessment (Buck & Trauth-Nare, 2009). Most importantly, teachers need to work together with students to build an atmosphere of trust inside the classroom.

Second, formative assessment depends on clear learning goals, tracking students’ progress, and using multiple methods of assessment. This necessitates an alignment between planning, instruction, and assessment. Teachers should communicate learning goals, tasks, and assessment criteria to students, while students need to understand what is expected so they can also track their progress and strive to accomplish the learning goals. In all of these tasks, metacognition plays an important role. Learning goals and goal tracking are related to the planning, monitoring, and evaluation tasks of metacognition (Schraw, 1989). Additionally, Flavell (1979) included goals and tasks as part of his metacognitive model. Experiences with and knowledge of metacognition help a learner to accomplish goals using strategies and tasks. Students need to learn how and when to use different strategies to accomplish learning goals, a fundamentally metacognitive process.

The third element of formative assessment involves eliciting students’ thinking, another form of metacognition. Some authors criticize research focused on formative assessment because it is considered more of an instructional strategy than an instrument to provoke thinking. Coffey, Hammer, Levin, and Grant (2011), after analyzing four transcripts from well-known research studies in this area, concluded that formative assessment is seen as a teaching strategy rather than a tool to promote student thinking and argumentation. Furthermore, Haug and Ødegaard (2015) concluded that teachers do not use students’ thinking to provide feedback or to adapt their instruction. Researchers
thus recommend focusing formative assessment studies on students’ thinking rather than on teaching routines or practices. In other words, teachers should use more metacognitive teaching strategies as tools to elicit students’ thinking and awareness, while research about formative assessment must also consider metacognitive processes.

As a fifth element, teachers must prepare students to work on formative assessment as an integral part of teaching and learning. This requires them to provide feedback on students’ learning and help them develop metacognitive skills to become independent learners. Furtak, Morrison, and Kroog (2014) came up with what they called a *formative assessment development cycle* to apply in the science classroom. In this cycle, teachers explore students’ ideas, focus their instruction, develop tools and activities, practice using the tools, enact the tools, and reflect on the enactment.

Additionally, Bell and Cowie (2001) closely studied how teachers use formative assessment, developing a model (see Figure 2.3) for science education. They call *planned formative assessment* (PFA) the assessment planned in advance of an activity and used to collect information from students about their learning progress. Generally, this assessment involves content matter or skills used during scientific practices. PFA occurs over an extended time frame and is iterative (i.e., it happens in cycles that can occur over and over). This type of assessment is often conducted with all students in a class and involves using a concrete strategy, such as answering questions, a quiz, or a concept map.

The *interactive formative assessment* (IFA) is an iterative process as well, but the information and actions are an immediate part of teaching. This form of assessment happens in a short time during instruction and usually is not planned in advance. It assesses individuals or small groups and includes not just the subject content but also the
social and personal aspects of learning (e.g., how students feel during an activity, what problems they face when working as a group).

Figure 2.3 Planned and interactive formative assessment (Cowie & Bell, 1999 in Bell & Cowie, 2001). Planned formative assessment consists of acting, eliciting, and interpreting information from students’ learning outcomes. Interactive formative assessment comes from classroom interactions when teachers notice, recognize, and respond to students’ evidence of learning. In all these processes, metacognition should be present.

Interactive formative assessment can potentially be considered an intuitive part of teaching (Bell and Cowie, 2001), but it is not. It requires a teacher to be aware of what is happening with students and to modify learning experiences or generate new ones. This awareness of learning requires metacognition from both teachers and students. Bell and Cowie (2001) suggest that it can be a difficult skill to apply for inexperienced teachers. Formative assessment requires several elements, including teachers’ content knowledge, pedagogical content knowledge (PK), and personal characteristics such as flexibility, tolerance to uncertainty, and risk-taking. Nevertheless, formative assessment is an essential part of teaching.
Formative assessment relies heavily on metacognition and reflective practices. McGregor (2011) explained that formative assessment requires reflection to help students elicit their thinking and to help teachers recognize students’ learning and modify their instruction when needed. Trauth-Nare and Buck (2011) concluded that reflective practices were important for developing students’ concepts of formative assessment, evaluating students’ learning, and creating instructional enhancements that support students’ conceptual development. Moreover, Bell and Cowie’s (2001) formative assessment model relates to Schön’s concept of reflection-in-action and on-action.

Reflection-in-action can be connected with interactive formative assessment because it is about on-the-spot decisions and actions in progress about learning. Similarly, planned formative assessment can relate to reflection-on-action by using specific learning tasks to gather evidence of students’ learning to inform teachers’ and students’ decisions.

To develop formative assessment skills, researchers recommend teachers acquire more student-centered beliefs, along with experience in mentoring (Aydin, Demirdogen, Tarkin, Kutucu, Ekiz, Nur Akin, Tuysuz, & Uzunkiryaki, 2013; Singer, Lotter, & Feller, 2011); teaching practice (Singer et al., 2011; Lakshmanan, Heath, Perlmutter, & Elder, 2011); and a learning environment combined with cognitive-metacognitive and motivational self-questioning (Michalsky, 2012). These elements can contribute to the development of beliefs and self-efficacy that will guide teachers’ future classroom performance.

For teachers, reflecting on their teaching using scientific practices and formative assessment can increase their knowledge about how to plan, monitor, and evaluate instructional strategies more effectively for students’ learning. Reflection is an instrument
that teachers can use to develop awareness about this process. Next, I describe reflective teaching practices as part of teachers’ experiences of metacognition.

**Metacognition and Reflective Practices**

As explained previously, reflection and metacognition have a deep connection. When researchers refer to thinking about teaching, they often prefer to use the term reflection or reflective practices (Marzano et al., 2010; McGregor 2011; Silver 2013). Reflection includes some habits or dispositions that are similar to metacognition, such as thinking about thinking and conducting an internal dialogue to plan, monitor, and evaluate an event. However, it also could include other habits, such as connecting information to new learning, applying insights to contexts, and acting on and processing information (York-Barr, Sommers, Ghere, & Montie, 2006). Consequently, I will describe reflection in the context of teaching as a practice or experience of metacognition that can increase knowledge of metacognition.

Teaching is a skill, and like any skill, teachers need practice and effort to develop expertise (Marzano et al., 2012; McGregor, 2011). Reflective practices can help teachers develop this expertise by looking back on their teaching practices, setting goals, focusing their practice on certain elements they want to develop, and using feedback to achieve goals (Marzano et al., 2012). In this process, teachers can connect theory with their experiences to develop practical wisdom and work with others to strengthen their reflection. Reflection and reflective practices developed as a prominent research area after the work of scholars such as Kurt Lewin, a social psychologist who introduced action research in the 1940s, and Donald Schön in the 1980s. Schön’s work can be
applied to an extensive number of disciplines, but it is especially relevant to those which are complex in nature, such as teaching.

**Reflection and Teaching**

Reflection has commonly been considered an important skill for teaching. As with metacognition, we cannot directly observe a reflective practice. However, it can manifest in actions (e.g., adopting a teaching practice; reflection in action) or in discourse (e.g., talking about teaching practices; reflection on action) (Collin et al., 2013). Like other complex constructs and terms, there is still discussion and a lack of agreement about what reflective practice is (Collin et al., 2013). For this study, I will not go into detail about possible semantic differences or make distinctions between reflection, reflective practices, or reflective thinking. Instead, I consider them synonyms that are all part of teachers’ experiences of metacognition.

Toom, Husu, and Patrikainen (2014) defined teachers’ reflective thinking as “an essential skill for identifying, analyzing, and solving the complex problems that characterize teachers’ classroom work.” (p. 321). Korthagen and Vasalos (2005) described teachers’ reflections as thinking about their teaching environment, behaviors, competencies, and beliefs about teaching and learning. Reflection in the context of teaching means to “look back” or “think back” at actions and teaching strategies and being able to assess them after something unexpected or uncommon has happened (Korthagen & Vasalos, 2005; McGregor, 2011). In addition to the assessment of teaching strategies, reflection can also include lesson planning and tracking of those plans, which falls under the definition of metacognition. However, reflection also has a strong connection with experiences and teaching improvement. For instance, McGregor (2011)
explained that reflection is especially important after something unexpected or out of the ordinary has happened in the classroom. This role echoes Dewey’s concept of reflective thinking, which begins after a problem.

As research has shown, a problematic or unexpected situation in the classroom should not necessarily have a negative connotation. Lane, Mcmaster, Adum and Cavanagh (2014) explained that reflective thinking can begin when a teacher notices a positive or negative event, incident, or situation of concern. A situation of concern might lead to the implementation of a new teaching strategy, for example. Therefore, Lane et al. (2014) consider reflection a “deliberate cognitive process” (p. 482) because the person performing it should have an interest or a need.

Korthagen and Valsos (2005) proposed the ALACT model used by researchers (e.g., Cartwright, 2011; Marzano et al., 2010) to explain reflection in the context of teaching (Figure 2.4). The cycle begins with a problematic situation, an event, or something that the teacher wants to change or improve (Step 1). It requires looking back on the action (Step 2) to analyze and develop awareness of the essential aspects that produced the original situation (Step 3). Next, the teacher comes up with alternative methods or strategies. Here, knowledge and creativity become important elements. Finally, the teacher implements the new plan and evaluates its efficacy to solve the original problem, which can generate a new reflective cycle.
Figure 2.4 The ALACT model (Korthagen & Vasalos, 2005). Teachers begin reflection with an action, problem, or situation of concern. Next, they look back to develop awareness of the aspects that could influence the situation in order to create an alternative method of action and implement it. It is a cycle because after the trial of the new course of action, the teacher can begin the process again.

Researchers agree on the importance of reflection for teachers, as reflective practice can improve teaching and learning in the classroom (Belvis, Pineda, Armengol, & Moreno, 2013; Cartwright, 2011; Korthagen & Vaslos, 2005; Larrivee, 2008a; Lunenberg & Korthagen, 2009; McGregor 2011). Reflective practices serve an extended range of purposes and can help teachers “to describe practices ranging from analyzing a single aspect of a lesson to considering the ethical, social, and political implications of teaching practice” (Larrivee, 2008a p. 341). Therefore, reflective practices go beyond competencies or behaviors only. They can also include the ethical, social, or power relationships affecting teaching and learning.
Reflection is especially important for teachers during their first years in the classroom. McGregor (2011) explained that new teachers usually use reflective practices to become more effective, develop engaging lessons, and understand what works well in the classroom. It is challenging for a beginning teacher to master the curriculum and necessary pedagogical knowledge when teaching a course for the first time (Mycroft & Gurton, 2011). Beginning teachers are learning how to apply their knowledge and skills from teacher education programs within the context and needs of their new school and students while developing practical wisdom (Figure 2.5).

![Figure 2.5 Model of teachers’ practical wisdom (Lunenberg & Korthagen, 2009). Teachers use theory and experience to enhance practical wisdom, which will help to inform their experiences and knowledge.](image)

Practical wisdom develops when a teacher makes connections between experiences and theory and is defined as “the sensitivity for and awareness of the essentials of a particular practice situation that shape our perception of this situation, and help us find possible courses of action” (Lunenberg & Korthagen, 2009, p. 227). Practical wisdom requires teachers to use theory to inform and understand classroom experiences
related to teaching and learning. It also involves a deep understanding of teaching experiences and strategies as well as students’ reactions in a specific context, which occurs after a reflective process (Cartwright & Thomas, 2011). Reflection can thus help teachers develop practical wisdom.

**Figure 2.6 Onion model (Korthagen & Vasalos, 2005).** Reflection involves a person’s mission, identity, beliefs, competencies, and behavior. Inner levels affect outer levels and vice versa. Reflection occurs in context, and the environment can also influence the level of reflection.

Reflection also has a multifaceted nature (Toom et al., 2014), as it involves multiple aspects and elements of a person. It is much more than simply a rational thought exercise or looking back on a past event. Reflective practices should have a holistic approach and not just be intellectual or rational (Beauchamp, 2015; Cartwright, 2011; Korthagen & Vasalos, 2005). A meaningful reflection should balance the rational (i.e., logical thought) and the affective (i.e., feelings). Korthagen & Vasalos (2005) affirmed
that reflection should consider thinking, feeling, wanting, and acting. Moreover, it includes ethical (i.e., teachers’ moral principles), epistemological (i.e., how teachers generate new knowledge), and metaphysical (i.e., the origin of knowledge) bases for practice (Beauchamp, 2015). To explain the multifaceted nature and the diversity of content that a reflection could assume, Korthagen and Vasalos (2005) came up with the onion model (Figure 2.6).

The onion model describes different levels at which reflection can take place, based on its content (Korthagen & Vasalos, 2005). For example, the inner levels, which represent a deeper reflection, involve a teacher’s personal mission, identity, and beliefs. More superficial reflections involve competencies and behaviors. Inner levels affect outer levels, and vice versa (Korthagen & Vasalos, 2005). For example, personal experiences, cultural influences, hopes, and aspirations are all important parts of a teacher’s identity (Dunne, 2011), and thus can influence his or her competencies and beliefs about teaching and learning (i.e., knowledge, skills, and experiences with teaching). For this study, I focused my attention on the outer levels of the onion model, especially on teachers’ competency in teaching science.

Additionally, the environment and context where the reflection takes place has an important influence (Beauchamp, 2015, Korthagen & Vasalos, 2005). Beauchamp (2015) explained that reflection does not occur in isolation, but rather in a workplace or context that impacts teachers’ reflective practice. That is, a teacher develops reflective practices within a system (i.e., the school) which has its own set of rules, power relationships, and policies that will interact with the teacher’s mission, identity, beliefs, competencies, and
behaviors. Therefore, reflective practice should be understood in relationship to the broader social context where it takes place (Beauchamp, 2015).

The onion model of reflection emphasizes the contents of the reflective process. Other scholars have proposed different classifications of levels of reflection to understand teachers’ reflective practices, which I explain in the next section.

**Levels of reflection.** Reflection is a complex construct that can involve actions, feelings, beliefs, hopes, and experiences. In order to gain a better understanding of the qualities of reflection, some scholars have suggested different classifications of levels or stages of reflection (Cartwright, 2011; Larrivee, 2008a). Collin et al., (2013) criticized using levels of reflection because this could lead to label certain reflective practices as “good” or “bad” or to elevate certain levels of reflection above others. These authors explained that, from a pragmatic point of view, all levels of reflection could be useful for teachers, depending on the “pedagogical circumstances” (p. 110), the students’ needs, the context in which the teachers reflect, or even their reflective skills. On the other hand, Korthagen & Vasalos (2005) explained that using levels can help teachers improve the structure of their reflection and promote increased competence. Additionally, levels help to determine problems and promote change. The researchers explain that reflection about the inner levels of the onion will have a greater impact on the outer levels and will bring more perdurable changes. Cartwright (2011) also found that levels of reflection are helpful as a starting point in moving forward in reflective practices.

I decided to base this study on Cartwright (2011)’s levels of reflection, which emphasize how teachers’ awareness of experiences and theories inform their thinking about their practice. Other classifications of levels of reflection were similar (e.g.,
Larrivee, 2008a). However, I decided to use this classification because it included only three levels, the indicators were clear and easy to apply, and it emphasized the use of theory and experiences.

Cartwright’s model (2011) described three levels of reflection: (a) unconscious reflection, (b) conscious informed reflection, and (c) conscious critical reflection, all of which I explain in the following sections.

(a) **Unconscious reflection**: Teachers in this level of reflection include common-sense thinkers. They feel comfortable using trial and error during their lessons and accomplishing tasks for the present. They use the metaphor of a teacher as “transmitter of knowledge” and are more oriented toward teacher-centered models of instruction. Reflections are based on their experiences as students, so for them, good teaching means what they previously enjoyed or view as common sense. They rely on intuition when talking about school experiences, needing no more evidence than the knowledge that the lesson ran “smoothly.” Teachers using this level of reflection have little or no self-doubt about their judgments and consider their thoughts to be the correct way. They do not question their knowledge or beliefs or consider other points of view or alternative courses of action. They tend to make unsustained judgments and sweeping generalizations (e.g., “girls are not good in math”). Their reflections are focused on their own feelings.

(b) **Conscious informed reflection**: Teachers using this reflection base their thinking in experiences, evidence, and data. They analyze and dig beneath the data to draw conclusions. They appreciate other views and strategies for teaching, and they understand that there are different ways to teach the same content, seeking support
form a range of different sources (e.g., observing other teachers, looking for ideas in
different sources). They can reflect in action based on a growing set of experiences
that help them to support their arguments and judgments. They value being well-
inform ed about the school, the students, the context, and their prior learning, as they
utilize this information to have a better understanding of their teaching strategies.
Teachers using this level of reflection can deconstruct knowledge based on their
prior experiences as students, now with a new meaning and perspective as teachers.
These teachers seek to differentiate learning, evaluate their own practice, and
establish new ways of working as a result. They recognize their own feelings but
also consider how their behavior affects students or other colleagues.

(c) **Conscious critical reflection**: Thomson and Pascal (2012) call teachers in this level
“knowledgeable doers,” because they invite an open dialogue between theory and
practice; consider knowledge, skills, values, emotions, and experiences used in
practice and needed for learning; promote the participation of others and the
consideration of power relations; and challenge dogma through open-mindedness.
Moreover, this level of reflection can promote creativity. The word “critical” within
this level relates to critical thinking, awareness of power relationships, and social
justice. These teachers use teaching and learning theories and models to inform their
reflections and to think about their goals and efficacy, using educational theories to
inform their planning, teaching, and evaluation. Teachers in this level also recognize
that there are different ways to approach a problem, yet they understand where they
stand and why. Their reflections may evaluate different sources of information;
consider their validity, reliability, and personal biases; issue challenges from a
position of knowledge and understanding; and compare and contrast theories. These teachers take risks but are willing to evaluate them rigorously and acknowledge when things have not gone well. Teachers in this level are additionally open to criticism, proactively seek knowledge and understanding, and are willing to take into account the viewpoint of others.

Edwards and Thomas (2010) considered reflection an essential part of teaching practice. They argued there is no need to teach others how to reflect since it is considered part of human nature, an element for learning as a social “self-corrected inquiry” (using Dewey’s concept), and embedded in practice. That is, teachers will reflect even if they are not required to do so because it is an inherent part of their practice. On the other hand, Hostetler (2016) suggested that teachers should first be virtuous practitioners (i.e., able to perceive and recognize what is right or good for students while they are teaching) rather than reflective practitioners. However, there is a general agreement that reflection is important for teaching and that certain elements can help teachers deepen their level or quality of reflection (Cartwright, 2011; Corsi, 2010; Larrivee, 2008a; Larrivee, 2008b Malthouse et al., 2014). These include collaboration with others, facilitation and school leadership, the context where the reflection takes place, the use of models, or the use of strategies such as writing.

As with metacognition, reflection requires collaboration (Larrivee, 2008b), since collaboration can deepen teachers’ level of reflection and encourage more critical awareness (Gault, 2011). Edwards and Thomas (2010) defined reflection as “inherently social.” The potential for reflection to enhance teaching practice is also social, as it is conducted in collaboration. Similar to learning, reflection can potentially be perceived as
individualized and isolated, but its nature is inherently social. Therefore, working with others and reflecting together is an essential part of reflection, which happens when teacher collaborate.

York-Barr et al. (2006) viewed reflective teaching as related to collaboration and practice. They came up with the idea that reflection can be performed in four interconnected levels of a spiral that includes individual reflection, reflection with partners (e.g., another teacher, a mentor), reflection in a small group or team, and finally, school-level reflection practice that can result in a “cumulative effect on school wide practices and learning” (p. 21). The authors believe that the outer levels of this spiral (i.e., school and group reflection) will be more effective because they will create a supportive environment for teachers to grow and adopt a specific practice.

However, researchers also find that facilitation can enhance reflection (Korthagen & Vasalos, 2005; Larrivee, 2008b; Marzano et al., 2012; York-Barr et al., 2006). This refers to a person in a leadership position, such as a learning facilitator or social mediator, who can help teachers set goals, focus their teaching practice on certain elements, and provide feedback (Marzano et al., 2012). Larrivee (2008b) explained that without carefully constructed scaffolding, prospective, novice, and even more experienced teachers are unable to engage in higher-order reflection to enhance their practice. Korthagen and Vasalos (2005) supported this finding. They noted that because teaching is demanding, teachers who do not receive facilitation might tend to find a “quick-fix” for problems rather than locating the source of the dissonance.

Supervisors, school administrators, and colleagues can help teachers in the role of learning mediators (Korthagen & Vasalos, 2005; York-Barr et al., 2006). However,
mediation requires a supportive environment. Larivee (2008a) explained that “even novice teachers can deepen their level of reflection with powerful facilitation and mediation within an emotionally supportive learning climate” (p. 346). In other words, a learning facilitator can promote reflection, but the context in which these reflections take place will also impact the level of reflection.

Edwards and Thomas (2010) considered teachers’ reflection context the most important element as part of a social process. The context where a reflection takes place can include the physical surroundings (e.g., the environment, the layout, how teacher access information), the social settings (e.g., how people interact in the school, roles, responsibilities, expectations, goals) and individual dispositions (e.g., personal dispositions, skills, competencies, mood, experience) (Malthouse et al., 2014). All of those elements interact and contribute to the quality of reflection. A supportive environment not only enhances reflection, but can also provide agency for novice teachers to take risks and use innovative classroom strategies (Allen, 2009).

Finally, a structured reflection can also help teachers develop their reflection competencies (Corsi, 2010; Korthagen & Vasalos, 2005). Researchers (e.g., Cartwright, 2011; Larivee 2008b) have suggested strategies to help teachers develop as reflective practitioners, such as journal writing, the analysis of narratives (e.g., case story writing, metaphors, autobiographies) or critical incidents (e.g., real world examples with a dilemma), professional development, and the use of instructional models that include reflective practices. Belvis et al. (2013) suggest defining and systematizing teachers’ reflective practices and connecting them with their actions in order to support teaching and learning in the classroom.
This study sought a better understanding of the metacognitive knowledge and experiences of beginning science teachers. I considered reflective practices as experiences of metacognition because they can increase teachers’ knowledge of metacognition after using a scientific practice. In the next section I describe studies related to the impact of metacognition in science education.

**Metacognition and Science Education Research**

Metacognition occurs after the interaction of knowledge and experiences related to cognitive tasks and goals. In teaching science as inquiry, metacognition is important for reflecting about learning, but also for thinking about how science generates new knowledge. A body of existing research has explored the connection between metacognition and science research, as outlined in the following paragraphs.

Memnum (2013) administered the Metacognitive Awareness Inventory (MAI) developed by Balcikanli (2011) to assess metacognition among 215 pre-service elementary school teachers (freshmen and sophomore college students) in Turkey and the United States. After his study, the author concluded that metacognition provides advantages for learning. Memnum (2013) contended that “individuals who are aware of their metacognitive ability are more strategic in problem solving than those who are not” (p. 277). High metacognitive awareness enables teachers to be more successful in their professional lives and support students’ learning by providing opportunities for them to develop and increase their metacognitive awareness (Memnun, 2013, p. 279). In other words, teachers who are themselves metacognitively aware can create more opportunities for students to develop their own metacognition.
In another study, 12 volunteer elementary pre-service teachers participated in a professional development workshop about forces (Parker & Heywood, 2013). The researchers gave the teachers reflective questions to respond to after the lesson and recorded their discussions. The authors concluded that training can help elementary student teachers develop metacognitive awareness of their own learning, relate this information to their elementary curriculum, and formulate pedagogical insights about their teaching. They recommended that science teacher education programs promote a reflective environment in order to increase metacognitive awareness in teachers.

Thomas and Anderson (2014) created an intervention involving metacognition in learning environments with a high school chemistry teacher and [her] students. The authors used a mixed-methods approach that included two tests administered to 33 students, classroom observations, student and teacher interviews, and artifact analysis. The authors concluded that in order to promote learning in three types of chemistry knowledge (macro, micro, and symbolic), teachers need to develop and enhance students’ metacognition: “There is a need for teachers to teach students about the meta-structures and representations that underpin learning and understanding their subject areas. Further, teachers need to develop classroom environments that are conducive to the development and enhancement of students’ metacognition” (p. 153).

Ben-David and Orion (2012) conducted a study of 44 elementary science teachers from 18 different schools in Israel (urban and peripheral) with a wide range of teaching experience, beginning their research after the teachers attended a professional development (PD) based on metacognition. The researchers recorded all of the discussions during the PD, analyzed the written reflections, and interviewed three
participants. They found that most teachers (91%) were previously completely unfamiliar with the concept of metacognition. Teachers expressed two specific barriers that might prevent them from integrating metacognition a part of their science instruction: “(1) the lack of appropriate learning materials and (2) the absence of close, supportive in-classroom guidance” (Ben-David & Orion, 2012, p. 3186).

Mai (2015) studied 52 elementary teachers in Ipoh-Malaysia and found that metacognition is important for teachers to adapt their instruction based on students’ needs. He used the term “metacognitive teaching” to refer to teaching with and for metacognition. This involves teachers thinking about their own thinking regarding instructional goals, teaching strategies, sequences, materials, students’ characteristics and needs, and issues related to curriculum, instruction, and assessment before, during, and after lessons. He used an adapted version of the Metacognitive Awareness Inventory for Teachers (MAIT) and validated it to use it in a Malaysian educational context. He also conducted ANOVA tests to find significant differences in the metacognitive awareness of science teachers according to their gender, age, and educational level. The study found significant differences in metacognitive awareness depending on age, as teachers of ages 20-30 years had a higher metacognitive awareness than both teachers ages 31-40 and teachers aged 41 and above. He found that age interacted with educational level to explain teachers’ perception of metacognition (Mai, 2015). Results indicated that science teachers had strong perceptions about metacognition. They were aware of choosing the appropriate and effective teaching technique and setting goals before starting a lesson.

Spruce and Bol (2014) developed a study using multi-method data collection strategies to reveal teachers’ beliefs and knowledge about self-regulated learning (SRL).
They used a standardized survey (developed by Lombaerts et al., 2009) to obtain self-reports of teachers’ beliefs, classroom observations (with a protocol), and interviews based on Lederman’s work on self-regulation. The sample was composed of 84 teachers (elementary and middle school) with at least five years of teaching. They chose eight teacher volunteers to conduct the observations and interviews. The study found that teachers believed students might not be ready to self-regulate at the middle school level and realized this might have implications for classroom practice. The researchers concluded that if teachers do not believe their students are capable of self-regulation, this may limit their willingness to initiate activities offering students the opportunity to practice SRL in the classroom (Spruce & Bol, 2014). Despite expressing positive beliefs about SRL in the classroom, teachers’ SRL knowledge and instructional practices were considered low in general (1.97 was their average score out of a 0 to 4 scale in their observation protocol). Teachers commented that they had limited time and space in the curriculum for teaching learning process skills because of high content-specific demands.

Wilson and Bai (2010) constructed and administered a survey to 105 participants enrolled in a graduate-level education program in the Southeastern United States. The researchers assessed participants’ pedagogical understanding of metacognition, the nature of what it means to teach metacognition, and the relationship between participants’ knowledge and pedagogical understandings of metacognition. Results showed that teaching metacognition requires an active process of visible problem-solving. Teaching conditional metacognition was key in this process. Wilson and Bai concluded that teaching metacognitive thinking strategies is an active process, which also involves awareness of cognition: “Awareness is different from active learning because it only asks
students to know what or when a problem occurs” (Wilson & Bai, 2010, p. 281). The study findings suggested that “the individual teacher’s understanding of metacognition was related to the instructional strategies they perceived to be effective in helping students to become metacognitive” (Wilson & Bai, 2010, p. 285).

Moallem (1997) conducted a case study focused on the reflective teaching of Sarah, an experienced secondary science teacher. The researcher described elements that stimulated the participant’s reflective thinking: (1) her interest in meeting students’ learning needs, (2) her sense of being a learner, and (3) her desire to perform better as a teacher and help students master the curriculum goals and subject matter content, as well as assessing her instructional activities. Moallem (1997) suggested that professional development and teacher education programs should place more emphasis on teachers’ reflection-in-action. She contended that reflection was a part of the conceptual change process in teaching, as well as a way to restore the inconsistencies between teaching practices and beliefs. Moallem (1997) noticed that this teacher’s sense of freedom and flexibility in instructional decisions and curriculum affected her reflection upon her teaching. She concluded by recommending that schools provide time and opportunities for reflection in order to promote more reflective teachers.

Powell (1996) conducted a qualitative, four-year longitudinal study of two beginning teachers: one in English, the other in science. The purpose of the study was to explore the influence of biographical factors and personal beliefs (or worldviews) on the classroom learning environments teachers constructed during student teaching and their first two years as beginning teachers. Powell (1996) acknowledged that teachers’ worldviews and epistemologies (i.e., beliefs about the nature of knowledge) “are not
easily described by those who hold them” (p. 371). After four years of classroom observations, interviews, and informal conversations, he found three general themes that affected teachers’ decisions: (1) beliefs about teaching, (2) beliefs about students’ learning, and (3) influences on classroom curriculum. Within the study, the teacher who believed in integrating students’ backgrounds into the curriculum, giving students an active role in knowledge generation, and understanding students’ learning as subjective rather than content-driven performed a higher number of student-centered instructional activities. Therefore, Powell concluded that personal beliefs, worldviews, and epistemologies affect instructional decisions and teaching approaches.

Conclusion

In sum, metacognition comprises thinking about learning. It includes psychological and epistemological elements, both of which include declarative, procedural, and conditional knowledge that can guide the decisions and actions of teaching as inquiry. Metacognition contains an epistemic component as well, which considers how and why knowledge becomes valid. Knowledge of metacognition interacts with experiences of metacognition to increase the understanding and use of metacognitive practices. Teaching science as inquiry can be considered an experience of metacognition because it generally involves complex activities that require awareness and decision-making from both teachers and students. Furthermore, reflective practices are a metacognitive experience because they can increase a learner’s knowledge of metacognition, helping them use experiences and knowledge to inform their instruction and develop practical wisdom. Metacognition is more than merely individual introspection, but is also a social process that requires interaction among peers, teachers,
and students and involves formative assessment practices. Research has provided evidence that metacognitive awareness, beliefs, and worldviews affect teachers’ instructional decisions. Building on past scholarship, the current study intends to contribute to the understanding of how teachers’ metacognitive knowledge affects their practice.
CHAPTER 3: STUDY METHODOLOGY

In this chapter, I describe the theoretical perspective that guided this study, my position as a researcher, my selection of participants, data collection, and data analysis, all of which were designed to answer my research questions.

Theoretical Perspective

The theoretical framework informing my study draws upon cognitive and educational concepts from existing scholarship on conceptual change and socio-constructivist theories. The conceptual change theory has been studied extensively, especially to explain how learners can accommodate and assimilate scientific concepts. However, this theory can also serve as a lens for understanding how teachers learn to teach science (Feldman, 2000; Gregoire, 2003, Russell & Martin, 2014).

The conceptual change theory is an approach used to explain science learning (Amin et al., 2014). Posner et al. (1982) explained it as the description of the substantive dimensions by which a learner organizes a concept change from one set of concepts to another set, incompatible with the first, that produces new learning. The conceptual change theory describes how learners, in this case novice teachers, integrate new information to develop their own understandings and explanations of phenomena. It describes how learning works from a cognitive perspective, defining cognition as the mental process of acquiring knowledge. For teachers, the phenomenon under study could be learning how to teach science effectively or how to promote teaching science as inquiry.

The conceptual change theory explains that learners do not begin the learning process as “blank pages.” Instead, they have been in continuous contact with the natural
world, and therefore have prior knowledge, experiences, and background information that will help them to understand and assimilate new knowledge. Sometimes learners also have alternative conceptions or misconceptions about certain ideas. The learning process begins, then, when anomalies or discomforts appear between the learners’ “old” ideas or information and new experiences (Pintrich et al., 1993). This process encompasses the interaction between what the learner previously knew about a concept, idea, or construct, as well as the new information gained after a learning experience.

**Figure 3.1.** The conceptual change theory. Learning comes from a process of discomfort, awareness of prior and new knowledge, accommodation, misconceptions as a process of resistance, metacognition as awareness to those resistances, assimilation, and then new learning.

Change is produced when the learner realizes a need or a discomfort (Figure 3.1). Learning, as a process of change, requires an awareness of the differences between what was previously known and novice experience. New learning is produced after assimilation (integrating new ideas with old information) and accommodation (individual ideas, referred to as alternative frameworks, which make them resistant to change) (Pintrich et al., 1993; Duit & Treagust, 2003; Scott, Ashoko & Leach, 2007). The learner integrates new and old knowledge and compares alternative conceptions with prior knowledge. An alternative conception is a resistance to conceptual change (which is
common within a change process). Metacognition, then, can produce awareness of resistances and contribute to the process of learning development, since learners require awareness of the learning process (Duit & Treagust, 2003). In sum, metacognition helps learners to understand what they learn and how they manage learning difficulties or resistance.

In order to teach science as inquiry, and to connect with the NGSS’s stated purpose “to develop an in-depth understanding of content and develop key skills—communication, collaboration, inquiry, problem solving, and flexibility” (NGSS Lead States, 2013, paragraph 4), science teachers must elicit students’ reflection and thinking. Scientific thinking, defined as hypotactic-deductive reasoning employed through modeling, theory building, and revision (Amin et al., 2014), can be cultivated by applying NGSS scientific and engineering practices to generate new ideas. In other words, teachers need to provide opportunities for students to develop explanations and thus experience new learning through scientific practices, such as observations, questioning, data collection and analysis, scientific argumentation, and drawing conclusions in real situations. Through providing these opportunities for practicing science in school, students should develop knowledge and skills to understand the natural world and learn how to use science to solve everyday problems. Science teachers must promote and design environments and experiences where students can learn science as doing science. Metacognitive teaching practices can contribute to this development of students’ scientific thinking and understanding.

Moreover, conceptual change theory also explains the learning process of teachers, especially novice science teachers. They begin their first years of teaching with
prior ideas and beliefs that will frame their science teaching practices (Russell & Martin, 2014). Consequently, beginning science teachers might be involved in their own learning process and conceptual change of learning how to teach (Duffy et al., 2009), so new experiences will help them to frame and generate new ideas about science teaching.

Beginning science teachers have knowledge and beliefs about science teaching from their prior experiences (e.g., undergraduate studies, student teaching) and what they studied during their teacher education programs. Discrepancies might arise when they compare their beliefs and prior knowledge with the reality of their students and school context. During the first years of teaching, beginning teachers develop new learning from their experiences (Russell & Martin, 2014). Teaching using metacognition can be an effective alternative and an interesting challenge for teachers (Feldman, 2000). These new experiences should additionally be accompanied with thoughtful reflection on action and feedback (Feldman, 2000, Gregoire, 2003; Zembal-Saul, Krajcik, & Blumenfeld, 2002). They are part of the metacognitive process that will help teachers overcome resistance and be aware of these beliefs and learning processes.

Thus, science teachers, especially early in their careers, should be reflective professionals in order to understand their own misconceptions, resistances, beliefs, and prior knowledge, adapt to a new teaching context, and learn from what happens inside their classrooms in new school settings. Moreover, new teachers require sufficient knowledge, experiences (e.g., using teaching as inquiry or metacognitive strategies), and the resources to support their learning in order to implement teaching practices that will implicate changes in their science teaching beliefs (Feldman, 2000, Gregoire, 2003). Due to the many new experiences and challenges beginning teachers face, it is fundamental
for them to develop metacognitive awareness and reflective practices to understand their learning process. Therefore, practicing metacognition is essential in helping teachers develop new ideas, beliefs, and strategies about teaching science as inquiry. By employing metacognition and reflection about their teaching processes, science teachers are able to design and use their experiences to support students’ learning.

Metacognitive science teachers can also model how to learn based on the conceptual change theory and show students what it means to be a lifelong learner. Since experience and reflection help teachers learn, they can facilitate this same process among their students through scientific practices (Russel & Martin, 2014). If teachers understand their own thinking and learning processes, they will have the tools to respond to students’ needs, be models of lifelong learning, and support the development of scientific thinking for all.

**Research Paradigm**

In this study I employ a pragmatist approach to research (Morgan, 2007). This approach sustains methodological flexibility and multiple perspectives (Green & Hall, 2010) in serving the researcher’s goals. In a pragmatist framework, it is the researcher who “appropriates” the methods and questions (Morgan, 2007, p. 69). In other words, I use the necessary means to accomplish my research objectives, always operating within a strong ethical and moral framework. The key concerns of this approach include how much shared understanding can be accomplished, as well as what kind of shared lines of behavior might arise (Morgan, 2007). This shared understanding thus allows me to pursue my research questions.
A pragmatic approach is a result of one’s belief that truth comes from experience (Green & Hall, 2010). Therefore, I acknowledge that my experience, education, and background are likely to influence my understanding of the evidence gathered during the investigation, as well as my interpretation and production of findings. I recognize that “Human investigators are always imperfect and situated in social and historical contexts in which multiple motivations operate, and not just a disinterested pursuit of ‘truth’” (Phillips & Burbules, 2000, p. 34). My background and beliefs are the lenses that will help me to understand the phenomenon of metacognition among beginning science teachers.

**Position of the Researcher**

Throughout this study, I have remained aware of how my own unique positionality influences my research process. I come from a middle class, Mexican family of Spanish immigrants. My undergraduate major was food engineering, and I was always interested in teaching. I taught high school chemistry for 15 years at a private Catholic-funded school in Mexico. In my teaching career, I had opportunities to work with struggling students from both high and low socioeconomic status (SES). I began my career as an educational researcher in search of effective strategies for helping struggling high school chemistry students (especially those in poverty) and promoting reform-based instructional and assessment practices among high school teachers. As a part of my teaching beliefs developed over many years inside a high school classroom and working with science teachers, I consider the conceptual change framework an effective group of theories to explain teaching and learning in science. I also believe in Vygosky’s theories.
that learning is fundamentally social and thus requires consideration of the students’ context and classroom environment, as well as practicing care for all students.

Drawing on my background, experiences, and beliefs, in this study I explore beginning science teachers’ metacognitive knowledge and practices. As with every complex phenomenon, this requires an extensive data gathering phase and in-depth analysis. I hope this study will increase the field’s understanding of how science teachers’ metacognitive knowledge and practices can support students’ learning, especially those who struggle or come from diverse cultural and SES backgrounds. This study also addresses the need for generating instructional models that increase all students’ academic achievement in science education (Corsi, 2010). Finally, this study will help practicing teachers develop a more effective and nuanced understanding of how to work with particular student populations.

Research Design

I developed this multi-methods research project (Figure 3.2) while I was part of a larger longitudinal study at a Midwestern, state-funded university, which focused on the evaluation of science teachers to determine sources of effective teaching. I worked in this longitudinal study as part of a research group made up of one PI and three graduate students. For this larger study, we collected data from program alumni who volunteered to participate. Data collection practices included observing regular lessons, taking field notes, using different instruments to code classroom observations, and conducting and transcribing follow-up interviews. We visited each participating science teacher six times on average during the school year, although this number varied depending on the teacher’s needs. Most classroom observations were conducted in person. For teachers in
Figure 3.2 Multi-method research design for knowledge and practices of metacognition in beginning secondary science teachers. The gray squares represent the data collection phases for each research question (i.e., Q1, Q2, Q3, etc.). Arrows connect data collection and analysis.
schools more than 60 miles from the university, we watched video recordings they sent us or observed their classes via telecommunication software, such as Skype or FaceTime.

The participants in my dissertation study also participated in the larger project, and I employed some data from the large-scale study to support my findings. I will accordingly reference this parent study during the description of the participants, data collection, and analysis for the present study.

**Participants**

All study participants were beginning secondary science teachers (0 to 4 years of experience) in a state-funded, university-based, secondary science education program in a Midwestern city in the United States. The university has two science teacher education programs (TEPs): an undergraduate (UG) and a Master’s program (MAT).

For this study, I invited beginning secondary science teachers who fulfilled the following criteria:

a. Graduating from one of the two TEPs at this institution;

b. Providing the department with their contact information;

c. Teaching secondary science courses during the Fall 2016 semester (high school or middle school);

d. Agreeing to participate in the larger research study about the evaluation of TEPs between 2013 to 2016.

I followed the requirements of my university’s Institutional Review Board (IRB) each time I contacted or recruited participants for data collection (Appendix C). Accordingly, each teacher who agreed to participate signed a consent form (Appendix D) after each stage of data collection. I also requested research approval from participants’
districts and/or school principals before conducting interviews and classroom observations. I contacted 64 possible participants, 72% of whom had graduated from the Master’s program and 28% from the undergraduate program. I asked for departmental approval to use their contact information, although I had previous communications with these teachers before. I first invited them to answer a survey, after which I contacted 15 of them to conduct open-ended interviews.

I did not target a specific gender or socioeconomic status among participants, although I collected this information as part of the survey to better describe the participants and findings. I had also had prior professional contact or communication with most of the teachers I invited to participate, as I worked for four years as an assistant in the Master’s program; collected data (e.g., classroom observations, interviews, surveys) for the larger research study; participated in recruitment activities for the department; taught science teaching methods for graduate and undergraduate students; and supervised practicum and student teachers from 2013-2016.

At every stage of this project, I included only those teachers who voluntarily agreed to participate. I typically sent invitations via email, but occasionally invited participants in person. For example, I sent an email invitation to all potential participants asking them to answer the survey. Since I was visiting several teachers as part of the larger research study, however, I asked those participants for assistance in person. As part of the survey’s consent form, I also requested access to data collected for the large-scale study.
Individual participants’ and schools’ names were not identified during this study. I used aggregated data to present the results of the survey, as well as pseudonyms for the interview participants, in order to conceal their identities and teaching locations.

**Data Collection**

For this multi-methods study, I collected quantitative and qualitative data in order to triangulate information and acquire a better understanding of beginning teachers’ metacognitive knowledge and practices. I also used data from the larger research study. I asked participants to self-report and then corroborated the information they gave me with classroom observations. I chose this method because researchers in metacognition and reflective practices predominantly use self-reporting as their type of data collection (Dinsmore et al., 2008) and recommend triangulation of several sources for trustworthiness in studies based on self-reported data (Creswell, 2013; Duffy et al., 2009). Accordingly, I collected data using a standardized instrument (the MAIT survey), semi-structured interviews, classroom observations, and artifact analysis. I used four phases for data collection (Figure 3.1):

1. **MAIT survey**: In order to generate a range of perspectives from secondary science teachers and understand whether their knowledge of metacognition (i.e., metacognitive awareness) increased with years of teaching experience, I surveyed 36 program alumni. I used the software G*Power to determine the sample size needed (n=34), with power (β-1) = 0.80 and an effect size or $f^2=0.35$ (large effect). I did not use a random sample, as survey-takers volunteered to answer the questionnaire based on the invitations I sent them. Therefore, I recognize the possibility that science teachers interested in metacognition or reflective practices
might have agreed to answer the questionnaire more frequently than other teachers. Considering this restriction, I wanted to find out whether years of experience had any influence on secondary science teachers’ metacognitive awareness. Additionally, I wanted to understand whether teachers with higher metacognitive awareness or knowledge are more likely to promote metacognitive strategies in their science instruction. The survey was available from September 2016 to December 2016, and I sent reminders to the teachers every other week during these months. I ended the data collection when I received enough answers to have statistical power \((n=34)\).

The survey-takers were 36 out of 64 alumni who voluntarily answered the on-line questionnaire (i.e., 56%). In general, 31 participants self-reported as White or Caucasians, two as Hispanic or Latino, one as African American, one as Middle Eastern, and one as mixed race (White or Caucasian and Middle Eastern). 45% of participants were male, while 55% were female. 78% taught at the high school level, 14% taught at the middle school level, and 8% taught at both levels. Table 3.1 illustrates the demographics of survey-takers.

Table 3.1

<table>
<thead>
<tr>
<th>Description of MAIT Survey Sample (Percentages)</th>
<th>Gender (%)</th>
<th>Grade (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>First-year teachers ((n=3))</td>
<td>67</td>
<td>33</td>
</tr>
<tr>
<td>Second-year teachers ((n=13))</td>
<td>23</td>
<td>77</td>
</tr>
<tr>
<td>Third-year teachers ((n=4))</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>Fourth-year teachers ((n=10))</td>
<td>60</td>
<td>40</td>
</tr>
<tr>
<td>Fifth-year teachers ((n=6))</td>
<td>33</td>
<td>67</td>
</tr>
<tr>
<td>Total science teachers ((n=36))</td>
<td>45</td>
<td>55</td>
</tr>
</tbody>
</table>

* High school  ** Middle school
2. **Semi-structured interviews**: In order to understand beginning science teachers’ knowledge and practices of metacognition, as well as how they use metacognition in the classroom, I conducted semi-structured interviews with 15 participants. Although Creswell (2013) recommends interviewing at least 20 subjects for grounded theory studies, based on my study’s exploratory nature, time limitations, and difficulty finding participants, I decided to include 15 beginning science teachers. As a result, I did not develop a full model or theory, but rather assertions or hypotheses that could be tested in further studies. I initially invited 27 science teachers from the list of potential participants (i.e., purposeful sampling), seeking participants with all ranges of teaching experience. I sent them an email explaining the purpose of the study and a description of the interview, along with inviting a few participants in person after visiting their classrooms for the larger research project.

**Table 3.2**

*Participants’ Demographic Information (Qualitative Strand of Study)*

<table>
<thead>
<tr>
<th>Teacher**</th>
<th>Age</th>
<th>Education</th>
<th>Gender</th>
<th>Ethnicity</th>
<th>Years teaching</th>
<th>Level</th>
<th>SES School (% FRL*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paula</td>
<td>&lt; 25</td>
<td>MAT</td>
<td>Female</td>
<td>Middle Eastern</td>
<td>0</td>
<td>HS</td>
<td>Low (65)</td>
</tr>
<tr>
<td>Elsa</td>
<td>&lt; 25</td>
<td>MAT</td>
<td>Female</td>
<td>White</td>
<td>1</td>
<td>HS</td>
<td>High (6)</td>
</tr>
<tr>
<td>Frank</td>
<td>&lt; 25</td>
<td>MAT</td>
<td>Male</td>
<td>White</td>
<td>1</td>
<td>HS</td>
<td>Low (51)</td>
</tr>
<tr>
<td>Gina</td>
<td>&lt; 25</td>
<td>UG</td>
<td>Female</td>
<td>White</td>
<td>1</td>
<td>HS</td>
<td>High (16)</td>
</tr>
<tr>
<td>Kate</td>
<td>&lt; 25</td>
<td>UG</td>
<td>Female</td>
<td>White</td>
<td>1</td>
<td>HS</td>
<td>Low (44)</td>
</tr>
<tr>
<td>Lucy</td>
<td>31-35</td>
<td>MAT</td>
<td>Female</td>
<td>White</td>
<td>1</td>
<td>MS</td>
<td>Low (76)</td>
</tr>
<tr>
<td>Pam</td>
<td>31-35</td>
<td>MAT</td>
<td>Female</td>
<td>African-American</td>
<td>1</td>
<td>HS</td>
<td>High (30)</td>
</tr>
<tr>
<td>Steve</td>
<td>31-35</td>
<td>MAT</td>
<td>Male</td>
<td>White</td>
<td>1</td>
<td>HS</td>
<td>Low (56)</td>
</tr>
<tr>
<td>Henry</td>
<td>25-30</td>
<td>MAT</td>
<td>Male</td>
<td>White</td>
<td>2</td>
<td>HS</td>
<td>High (34)</td>
</tr>
<tr>
<td>David</td>
<td>36-40</td>
<td>MAT</td>
<td>Male</td>
<td>Latino</td>
<td>3</td>
<td>HS</td>
<td>High (16)</td>
</tr>
<tr>
<td>Emma</td>
<td>25-30</td>
<td>MAT</td>
<td>Female</td>
<td>White</td>
<td>3</td>
<td>MS</td>
<td>Low (60)</td>
</tr>
<tr>
<td>Betty</td>
<td>31-35</td>
<td>MAT</td>
<td>Female</td>
<td>White</td>
<td>4</td>
<td>HS</td>
<td>High (39)</td>
</tr>
<tr>
<td>Jean</td>
<td>31-35</td>
<td>MAT</td>
<td>Female</td>
<td>White</td>
<td>4</td>
<td>HS</td>
<td>Low (42)</td>
</tr>
<tr>
<td>Matt</td>
<td>36-40</td>
<td>MAT</td>
<td>Male</td>
<td>White</td>
<td>4</td>
<td>MS</td>
<td>High (18)</td>
</tr>
<tr>
<td>Mary</td>
<td>25-30</td>
<td>MAT</td>
<td>Female</td>
<td>White</td>
<td>4</td>
<td>MS &amp; HS</td>
<td>High (0)</td>
</tr>
</tbody>
</table>

* FRL: Free and reduced lunch
** I am using pseudonyms to protect the participants’ identity
Once teachers agreed to participate, I contacted their school principals or
districts, depending on the case, to ask for written research approval before
conducting interviews. I interviewed three participants using teleconference
software (Skype and FaceTime), three by phone, and nine in person. All of the
interviews were conducted outside school hours in public spaces (e.g., coffee
shops, the school library) or at my school office. I adapted the place and time for
interviews to participants’ needs and schedule. The interviews were recorded and
transcribed for analysis.

I interviewed teachers from September 2016 to February 2017.
Participants’ backgrounds are described in Appendix E and summarized in Table
3.2. Ten participants were female and five were male. Three taught middle school
(MS, 6th to 8th grade); eleven taught high school (HS, 9th to 12th grade); and one
teacher taught both middle and high school. Twelve interview participants self-
reported as Caucasian or Western European, one as Latino, one as African-
American, and one as Middle Eastern. Two participating teachers came from the
undergraduate program (UG), while thirteen came from the Master’s in education
program with an emphasis in science teaching (MAT) (Table 3.3). Twelve
participants worked in public schools, while one worked in a Catholic private
school. One taught in a non-traditional setting (a zoo); another worked in a
vocational academy (a partnership between the public school district and a
community college). Eight science teachers were working in schools with a high
rate of students in poverty (more than 40% of students receiving free and reduced
lunch) or with a low socio-economic status.
Interview participants had between 0 and 4 years of experience teaching science. Some of them additionally reported experiences that might have influenced their teaching, including scientific work or research, coaching, and informal science teaching.

Table 3.3

<table>
<thead>
<tr>
<th>Gender</th>
<th>Level</th>
<th>School</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Male</td>
<td>Female</td>
<td>SES</td>
</tr>
<tr>
<td>HS</td>
<td>MS</td>
<td>Both</td>
</tr>
<tr>
<td>MAT</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>UG</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>5</td>
<td>10</td>
</tr>
</tbody>
</table>

3. **Classroom observations from the larger study.** I was able to verify some of the metacognitive themes that arose in interviews, as some participants were part of the larger research project described previously. For example, at least three times over the past two school years (2015-2016 and 2016-2017), I had observed, written field notes, interviewed, and coded data from 11 out of 15 interview participants. Four of them were not participating in the larger research project at the time of my study (David, Jean, Elsa, and Gina), but all had participated in prior years, and I had visited all of their classrooms over the last four years (Appendix F).

Moreover, for the MAIT survey-takers who agreed to share data from the previous study, I used 287 lessons coded by the research group from 30 teachers participating in the larger study from August 2015 to May 2017. The research group coded the data after a process of calibration at the beginning of each year.
for validity and reliability purposes. Therefore, I used classroom observations conducted by the entire research group, not only those that I observed.

4. **Classroom observations**: Along with the observations I conducted for the larger study, I included additional classroom visits in my body of data. Based on the semi-structured interviews, I asked two participants with exemplary metacognitive teaching practices to allow me to observe them during two weeks of their regular science instruction. The first of these participants was Frank, a high school science teacher with two years of experience who taught 11th graders at a vocational academy for students from both public and private schools. Frank taught principles of engineering during my observation (November-December 2016) from a curriculum based on a nationwide science and engineering program for secondary students. The second exemplary teacher I observed was Mary, a middle school science teacher with five years of experience who taught 6th graders at a private school in a small Midwestern city. The course I observed was general science, and the topic she was teaching at that time was astronomy (January-February 2017).

Since I was looking for metacognitive teaching practices during these additional observations, I did not use a particular protocol. School principals provided research approval, and both participants signed new consent forms. These observations did not require parental approval letters because they focused on teachers rather than students, and I did not use video recording. I observed and audio recorded two weeks of regular instruction along with some of my debriefing conversations with teachers. I visited the same section each time in order to
observe each teacher with the same group of students and the same content. I also
had the opportunity to comment, reflect on, and have debriefing moments before
and after some of the lessons, which allowed me to ask questions about what the
teachers were doing and better understand what was happening during instruction.
Although I recorded some of these debriefing conversations, some of them were
unplanned and thus not recorded. To supplement my data, I wrote field notes
during my observations along with some post-observation memos. Finally, the
teachers shared artifacts used during their observed lessons.

For this study, I used the following research instruments:

1. **Survey**: To understand teachers’ knowledge or awareness (Ben-David & Orion,
   2012) of metacognition, I used a standardized survey: The *Metacognitive
   Awareness Inventory for Teachers* (MAIT) (Balcikanli, 2011) (see Appendix G).
   It is a standardized questionnaire with 24 Likert-based items (5 levels), adapted
especially for teachers from the *Metacognitive Awareness Inventory* (MAI)
(Schraw & Sperling Dennison, 1996). The scale has two subscales: knowledge of
metacognition and metacognitive regulation. Knowledge of metacognition
consists of three kinds of knowledge: declarative (knowing about things;
conceptions, beliefs, goals); procedural (knowing how to do things; strategies),
and conditional knowledge (knowing why and when; selectively allocating
resources). The second subscale measures metacognitive regulation, which
includes regulatory skills: planning (selecting strategies, setting up goals);
monitoring (self-regulation, awareness of task performance); and evaluation
(looking deeply at outcomes, comparing with goals and processes). The survey was delivered to the teachers electronically using Qualtrics, and I sent reminders every two weeks to increase participation. The survey-takers were asked to click on a consent statement and to give approval to use their data from the larger study. During this survey, I also collected participants’ demographic information.

2. **Semi-structured interviews**: I prepared an initial questionnaire protocol to conduct interviews about teachers’ metacognitive understanding and practices (Appendix H). After every interview, I wrote in-process memos to start the analysis of the information gathered. These memos helped me to evaluate and modify the questionnaire protocol used for the interviews when necessary. As a result, the interviews involved a simultaneous process of gathering and analyzing information and changed over time in response to my findings.

For example, I initially began the interviews by asking participants about metacognition. However, because metacognition can be a fuzzy concept (i.e., sometimes it is considered as an overarching concept, sometimes as part of reflection or self-regulation), I decided it was necessary to ask about participants’ understanding and practices of reflection and self-regulation as well. Moreover, to address the epistemological aspects of metacognition in science education, I asked teachers about their understanding of scientific thinking and the nature of science. To engage my research questions for the study, it was important to know how teachers understood metacognition in the context of an inquiry-based lesson, as part of achieving students’ scientific literacy.
All interviews were audio recorded and transcribed for analysis. I personally transcribed nine of them using MAXQDA and Express Scribe software. The Bureau of Sociological Research (BSAR) transcribed four additional interviews after approval from the university IRB. The interviews were between 43 and 82 minutes long (Appendix I).

3. Observations from the larger study: I was able to verify the ideas that most of the interviewees described when I visited their classroom as part of the larger research study. Additionally, I used 287 lessons observed and coded from August 2015 to May 2017 by my research group. One of the instruments the research group used to code classroom observations was the Electronic Quality of Inquiry Protocol or EQUIP (Marshall et al., 2010). This is a standardized instrument developed to assess inquiry-based instruction. The entire instrument assesses 19 indicators aligned with four constructs: instruction, discourse, assessment, and curriculum. As part of the assessment construct, there is one indicator that rates reflective practices. I used this instrument to analyze the lessons of teachers who answered the MAIT survey, gave me approval to use their data, and were participating in the larger program evaluation study.

4. Classroom observations and artifact analysis: I observed two secondary science teachers for approximately two weeks of their regular instruction. I visited the same section each time and audio recorded the lessons (Appendix J). I did not have an observation protocol, as my focus was the metacognitive prompts and actions the teachers conducted during science instruction. I generated field notes and memos after each lesson, as well as questions to ask the
teachers during debriefing. I analyzed the artifacts provided by the teachers (e.g., worksheets, handouts) during my classroom observations in order to look for metacognitive prompts and activities that promote student reflection.

**Analytic Methods**

The data analysis for this project was conducted separately and integrated at the end of the process in order to make claims in response to the study’s research questions. I hypothesized that metacognitive knowledge will increase with teaching experience and that teachers with knowledge and practices of metacognition will use more metacognitive teaching practices in their science classrooms.

![Diagram of data analysis process](image)

*Figure 3.3 Components of data analysis: Interactive Model (Miles & Huberman, 1994 as cited in Miles et al., 2014, p. 14). The model suggests four phases for data analysis: data collection, data condensation, data display, and conclusions. All these phases interact and complement each other.*

For the quantitative research strand, I used descriptive statistics to analyze the metacognitive awareness or knowledge of metacognition in beginning teachers. Based on the results of the MAIT survey (α=0.05), I conducted a regression analysis using the IBM software SPSS to test whether there was a linear relationship between years of experience and metacognitive awareness, as well as whether years of experience could be a
significant predictor (Table 3). I also tested other variables, such as gender, program, school SES, and level (high school or middle school), to see whether I could find a significant predictor or explain the variables that influence metacognitive awareness. I visited the Nebraska Evaluation and Research (NEAR) center in order to check my results and confirm my findings.

For the qualitative strand analysis, I used the interactive model suggested by Miles and Huberman (1994) as cited in Miles, Huberman, & Saldana (2014) (Figure 3.3). In general, I utilized two cycles of coding to reduce or condense the data gathered. First, I used protocol coding, identifying a list of indicators on the interviews’ data to reduce the data; next, I used a second cycle of open and focused coding, seeking patterns and attempting to generate or verify themes and assertions as well as to draw conclusions. In the following paragraphs, I explain in greater detail how I used this model for data analysis in order to answer my research questions.

As described previously, I invited beginning secondary science teachers, alumni from a state-funded TEP, to participate in this study. Based on the answers and characteristics (e.g., years of experience, gender) of those teachers who agreed to participate, I invited additional science teachers until I reached 15 participants. The participants’ descriptions and understanding of metacognition allowed me to better comprehend the occurrence of metacognitive knowledge and practices in beginning teachers with between 0 and 4 years of experience. The number of participants also allowed me to find saturation in the information provided (Merriam, 2009). I transcribed interviews during data collection and wrote in-process memos after each interview, identifying elements of participants’ knowledge of metacognition and ideas which I
found important for the study. I used these ideas to modify my interview protocol and to confirm, extend, or reject ideas from other teachers. I also wrote in-process memos about the different topics I was exploring, such as levels of reflection, teachers’ understanding of metacognition, scientific thinking, and observed metacognitive teaching practices.

In analyzing the interview transcriptions, I used MAXQDA to simplify the information (i.e., data condensation), using a coding protocol (Miles et al., 2014). I identified the participants’ definitions and understanding of the terms “metacognition,” “reflection,” and “nature of science,” along with their descriptions of how they used these terms in their classrooms. I also added “self-regulation” and “scientific thinking” after a few interviews, since I noticed that for some teachers, this was a more common or better-known term than “metacognition.” As I explained in the literature review, there is a conceptual binding between all these terms (Dinsmore et al., 2008; Duffy et al., 2009; Hofer & Sinatra, 2010). Therefore, I considered it appropriate to include all the different terms (metacognition, reflection, self-regulation, nature of science, scientific thinking) to explore teachers’ knowledge and practices of metacognition.

To acquire a general idea of participants’ understanding and knowledge of metacognition, I conducted a word count using MAXQDA, identifying the most common words related to participants’ definitions of metacognition. For this analysis, I first generated a “go-list” after a general word count of terms that appeared in participants’ definitions, then used this list to conduct a second word count. I came up with an image of the most frequent words used to define metacognition using the online site “Word it Out.” Finally, I used those words to provide a general definition based on teachers’ answers.
In addition to the word count, in a second cycle of coding I identified the ideas participants associated with metacognition. I then coded the metacognitive teaching practices they reported using in their regular instruction, comparing their self-reports with the classroom observations I conducted. I came up with a taxonomy for classifying practices in order to acquire a better understanding of the practices teachers were using and their level of complexity.

Table 3.4

| Levels of Reflective Practice Indicators (Cartwright, 2011) Used for Protocol Coding |
|---------------------------------|---------------------------------|---------------------------------|
| Unconscious Reflection (UR)    | Conscious informed reflection (CIR) | Conscious critical reflection (CCR) |
| Viewing learning as “transmission of knowledge” | Seeking support from different sources (e.g., readings, colleagues, observations) | Recognizing different ways of approaching a problem |
| Common sense, trial and error | Recognizing his/her own feelings | Using different learning strategies |
| Getting things done for now | Evaluating his/her own practice and modifying instruction | Using theory to inform teaching |
| Little evidence, but the lesson appeared to run “smoothly” | Using data to support teaching | Using the nature of science or scientific practices. |
| Using his/her experience as a student | Experience informs teaching | Taking risks, but being willing to evaluate the results |
| Accepting his/her intuition to assess effectiveness with little or no self-doubt | Using experience as student with meaning as a teacher | Making comparisons to other teachers or ideas |
| Considering only his/her own feelings | | Being open to other’s ideas and criticism |
| Using generalizations or unsubstantiated statements | | |

---
For practices of metacognition I used Cartwright’s (2011) levels of conscious critical reflection described in the literature review (Table 3.4). Each level was coded based on the descriptors suggested by the author to identify teachers’ metacognitive practices during our interviews. I used these descriptors as my codes (i.e., protocol coding) to identify participants’ levels of conscious reflection during open-ended interviews, based on the higher frequency of coded segments. That is, almost all of the participants had coded segments in all three levels, so the one with the most segments was the one I used to identify that interview. I then developed matrices relating experience levels with levels of conscious reflection in order to identify patterns (i.e., data display).

I also used York-Barr et al.’s (2006) spiral of reflection to describe how exemplary beginning teachers practice metacognition and find patterns or relationships with their reflection awareness and knowledge of metacognition. The spiral of reflection explains reflective teaching practice as four interconnected levels or a spiral that moves from individual reflection (e.g., thinking alone about his/her practice), reflection with partners (e.g., talking with another teacher or mentor about teaching practices), reflection in a small group or team (e.g., a group of people or teachers), and finally, school-level reflection practice (e.g., teachers in the school participating in professional development or reflecting on a special topic promoted by the school administration). I analyzed teachers’ answers to identify which level of this spiral they reflected. The authors identify the outer levels (i.e., group and school reflection) as more effective for reflective practices and improvements than the inner levels (i.e., individual and with partners).
For the second cycle of coding, I used teachers’ descriptions and reflections on metacognition, reflection, self-regulation, the nature of science, and scientific thinking gathered from the semi-structured interviews. I employed open, in vivo, and focused coding, similar to a grounded theory analysis approach. The goal of this analysis was to generate claims and potential hypotheses that could serve as the foundation for a future line of research (Figure 3.1). Based on the number of participants in this project, I could not apply grounded theory or selective coding to confirm my findings.

The initial or open coding first served to generate labels to organize the data (Strauss and Corbin, 1998, cited in Creswell, 2013; Charmaz, 2006; Merriam, 2009) from the first five interviews. Next, I used focused coding to, as Charmaz (2006) describes it, “pinpoint and develop the most salient categories” (p. 46) and explain larger bodies of data. This coding helped me to generate themes and eventually assertions that could be testable in further studies. The focused coding also helped me to compare emerging data with the initial code system and refine it. I tried to stay focused on the data and seek participants’ understandings during analysis, applying Charmaz’s (2006) recommendations for coding in grounded theory (Table 3.5).

I employed short codes while comparing data, attempting to remain open and give participants a voice. I also used gerunds in my code names to provide a sense of action, especially in the description of metacognitive practices (Charmaz, 2006; Miles et al., 20014). MAXQDA helped me to conduct both coding cycles. I used a comparative approach, contrasting answers from participating teachers in order to identify central ideas related to the knowledge and practice of metacognition.
Table 3.5

A Code for Coding (Charmaz, 2006). Recommendations for Open Coding in a Grounded Theory Study

<table>
<thead>
<tr>
<th>A code for coding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remain open</td>
</tr>
<tr>
<td>Stay close to the data</td>
</tr>
<tr>
<td>Keep your codes simple and precise</td>
</tr>
<tr>
<td>Construct short codes</td>
</tr>
<tr>
<td>Preserve actions</td>
</tr>
<tr>
<td>Compare data with data</td>
</tr>
<tr>
<td>Move quickly through the data</td>
</tr>
</tbody>
</table>

During the process of data collection and analysis, I used memos to illustrate thoughts and connections I developed throughout the interviews and classroom observations (Charmaz, 2006). I composed in-process memos after all participant interviews, completing these memos after the first coding cycle (protocol coding). I also developed analytical memos for each level of conscious reflection, the spiral of reflection, and metacognitive practices, in order to describe each of these topics and develop vignettes to support my claims.

Figure 3.4. Grounded theory analysis. The analysis process starts with a cycle of open coding, based on the categories found in interviews. Axial coding reviews those categories after more interviews and uses the participants’ context and intervening conditions to establish causal conditions of the phenomena. Finally, selective coding uses the categories found to build a figure which represents the theoretical model.
For classroom observations coded for the larger study, I used the scored lessons from participants who agreed to share their data from the MAIT survey. I focused on the indicator “student reflection,” one of the assessment factors, to verify how frequently the participants were using metacognitive teaching as part of their science instruction.

The EQUIP has a scale of 1 to 4 to rate each indicator (Table 3.6). From the total of lessons coded, the mode was 1, which means participating teachers often did not explicitly encourage their students to reflect on their learning. However, 21% of the lessons coded (i.e., 62 lessons) had a 2 or a 3 in the reflection indicator. This gave me a small number of lessons to analyze more closely. Therefore, I decided to classify them as “MT” (i.e., using metacognitive teaching) when the lesson was rated as 2 or 3 in this indicator, or “No MT” (i.e., not using metacognitive teaching) when the lesson had a 1.

Table 3.6

**EQUIP Scale on Student Reflection (Marshall et al., 2008)**

<table>
<thead>
<tr>
<th>Construct measured</th>
<th>Pre-inquiry (level 1)</th>
<th>Developing inquiry (level 2)</th>
<th>Proficient inquiry (level 3)</th>
<th>Exemplary inquiry (level 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A3. Student reflection</td>
<td>Teacher did not explicitly encourage students to reflect on their own learning.</td>
<td>Teacher explicitly encouraged students to reflect on their learning, but only at a minimal knowledge level.</td>
<td>Teacher explicitly encouraged students to reflect on their learning at an understanding level.</td>
<td>Teacher consistently encouraged students to reflect on their learning multiple times throughout the lesson; encouraged students to think at higher levels.</td>
</tr>
</tbody>
</table>

The research group rated the student reflection indicator as an explicit instruction from science teachers to students. Each year we went over a process of calibration for validity and reliability purposes. I am aware that this indicator might not be identical to what I have described as metacognitive teaching. That is, the research group might not
have included in their definition of reflection all the purposes, modes, and outcomes that I have described. For example, the research group most likely did not classify teachers’ thinking aloud as a reflective practice. However, these numbers nevertheless provide a general idea of how often teachers include some form of reflection in their lessons. I also used field notes from participants’ lessons to verify ideas.

Table 3.7

<table>
<thead>
<tr>
<th>Research questions</th>
<th>Data collected</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. What is beginning secondary science teachers’ understanding of metacognition?</strong></td>
<td>MAIT survey, Interviews</td>
<td>Linear regression analysis; protocol, open, and focused coding for themes</td>
</tr>
<tr>
<td><strong>Specifically,</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. To what extent are these teachers aware, or unaware, of their knowledge of metacognition?</td>
<td>MAIT survey</td>
<td>Linear regression analysis</td>
</tr>
<tr>
<td>b. What do participants understand about metacognition (knowledge of metacognition) as an element for science teaching?</td>
<td>Interviews</td>
<td>Protocol, open, and focused coding for themes</td>
</tr>
<tr>
<td><strong>2. What are the common instructional practices of metacognition (i.e., metacognitive teaching) in beginning science teachers?</strong></td>
<td>Interviews and classroom observations</td>
<td>Protocol, open, and focused coding for themes</td>
</tr>
<tr>
<td>a. What elements do teachers believe affect their instructional practices of metacognition (or metacognitive teaching) as part of science instruction?</td>
<td>Interviews and classroom observations</td>
<td>Protocol, open, and focused coding for themes</td>
</tr>
<tr>
<td><strong>3. What are their reflective practices as experiences of metacognition?</strong></td>
<td>Interviews</td>
<td>Protocol coding</td>
</tr>
<tr>
<td>a. What factors could affect beginning science teachers’ reflective practices?</td>
<td>Interviews and classroom observations</td>
<td>Protocol coding and EQUIP frequency analysis</td>
</tr>
<tr>
<td><strong>4. What knowledge and experiences of metacognition affect teachers’ instructional practices of metacognition (or metacognitive teaching)?</strong></td>
<td>Interviews, classroom observations, artifact analysis</td>
<td>Open coding</td>
</tr>
</tbody>
</table>
Finally, during the two weeks of classroom observations I verified the metacognitive teaching practices described by participants and used some of the other data from the analysis to explain these practices. I analyzed field notes to identify moments where teachers used metacognition as part of their science instruction. I also identified the metacognitive practices and instructions in the handouts used by these participants. Additionally, I integrated some elements of the prior analysis in order to answer my research questions and verify some of the assertions. The timeline of research activities is summarized in Appendix K.

In summary, I present in Table 3.7 the research questions, data collection, and method of analysis I used to answer each question. In the following chapter, I present the results and discussion based on the research questions that guided this study.
CHAPTER FOUR: RESULTS

To gain a better understanding of beginning secondary science teachers’ knowledge and practices of metacognition and their use of metacognitive teaching practices, I conducted this study using two approaches. First, I employed a quantitative design, including administering a survey to describe participants’ knowledge or awareness of metacognition, analyzing quantitative data using a linear regression to find variables that could affect knowledge of metacognition, and using coded classroom observations as part of a larger research study. Second, I utilized a qualitative design to interview teachers in order to analyze their understanding of metacognition and practices of and for metacognition (experiences and metacognitive teaching), as well as conducting classroom observations and artifact analysis. I describe the findings using the research questions that framed the project. I have bolded some sentences and words in the participants’ excerpts to highlight important ideas within those vignettes.

Research Question #1:

What is Beginning Secondary Science Teachers’ Understanding of Metacognition?

To answer this question, I used qualitative and quantitative approaches and their associated data analysis. I will first present the quantitative analysis to describe beginning secondary science teachers’ knowledge or awareness of metacognition and variables that might affect metacognitive awareness. To describe participants’ understanding of metacognition and practices, I used qualitative data from the semi-structured interviews.

More specifically, the question asks: to what extent are these teachers aware, or unaware, of their knowledge of metacognition? To answer this question, I used the MAIT survey (Balcikanli, 2011).
The sample included 36 participants, of which 8% were first-year teachers or teachers with no prior experience, 36% were second-year teachers or teachers with one year of experience, 28% had three years of experience, and 17% had four years of experience. 36% percent of participants reported teaching one subject (e.g., biology, chemistry, general science, or ESS) during the time they answered the MAIT survey, while 64% reported teaching more than one subject. Participants revealed they were teaching a range of science subjects in secondary education (Table 4.1), the most common of these being biology (30%), physics (24%), and chemistry (16%).

Table 4.1

<table>
<thead>
<tr>
<th>Subject*</th>
<th>Biology (%)</th>
<th>Chemistry (%)</th>
<th>Physics (%)</th>
<th>ESS (%)</th>
<th>Other** (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First-year teachers (n=3)</td>
<td>20</td>
<td>20</td>
<td>40</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>Second-year teachers (n=13)</td>
<td>33</td>
<td>12.5</td>
<td>25</td>
<td>17</td>
<td>12.5</td>
</tr>
<tr>
<td>Third-year teachers (n=4)</td>
<td>12.5</td>
<td>25</td>
<td>25</td>
<td>12.5</td>
<td>25</td>
</tr>
<tr>
<td>Fourth-year teachers (n=10)</td>
<td>36</td>
<td>18</td>
<td>18</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>Fifth-year teachers (n=6)</td>
<td>27</td>
<td>9</td>
<td>27</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Total science teachers (n=36)</td>
<td>30</td>
<td>16</td>
<td>24</td>
<td>14</td>
<td>16</td>
</tr>
</tbody>
</table>

*A teacher could teach more than one subject. 36% of teachers were teaching one subject during fall 2016 and 64% two or more different subjects.

** Other courses: general science (middle school), elective high school courses (e.g., forensic science, zoology, anatomy and physiology, psychology, microbiology).

Additionally, survey-takers were often teaching in more than two different content areas. For example, 39% of respondents reported teaching one course, while another 39% reported two different content areas (e.g., biology and chemistry or physical science and Earth and space science [ESS]). Moreover, 14% teachers reported teaching three different subject areas during Fall 2016 and 8% reported teaching more than four content areas. For example, one of the participants reported teaching biology or life science; physics or physical science chemistry; Earth and space science or geoscience,
and general science. Teachers in small schools often teach several science classes from different content areas.

Appendix L lists the means, standard deviation, modes, and percentages of teachers’ answers to the MAIT survey, based on Yousef Mai’s (2015) analysis protocol. The highest items included Item #15, “I use different teaching techniques depending on the situation (conditional knowledge)” (M=4.4, SD=0.5); Item #2, “I try to use teaching techniques that worked in the past (procedural knowledge)” (M=4.3, SD=0.5); and Item #18, “After teaching a point, I ask myself if I’d teach it more effectively next time” (evaluation) (M=4.3, SD=0.6). For Item #2, the average increased as years of teaching experience increased. The average of first-year teachers for item #2 was 4.0, while fifth-year teachers’ average for the same item was 4.5. Teachers with more teaching experience tended to use more strategies than first-year teachers and had greater awareness of strategies that worked or did not work.

Table 4.2

Knowledge of Metacognition and Metacognitive Regulation Average and Standard Deviation Based on MAIT Survey

<table>
<thead>
<tr>
<th>Years of experience</th>
<th>Knowledge of metacognition M (SD)</th>
<th>Metacognitive regulation M (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Declarative Procedural Conditional</td>
<td>Planning Monitoring Evaluation</td>
</tr>
<tr>
<td>0 years (n=3)</td>
<td>4.1 (0.8) 3.8 (0.8) 3.8 (1.0)</td>
<td>3.5 (0.8) 3.8 (0.8) 3.7 (1.0)</td>
</tr>
<tr>
<td>1 year (n=13)</td>
<td>4.0 (0.6) 3.9 (0.7) 3.9 (0.8)</td>
<td>3.8 (0.7) 4.1 (0.6) 3.9 (0.6)</td>
</tr>
<tr>
<td>2 years (n=4)</td>
<td>4.1 (0.7) 3.9 (0.9) 4.0 (0.7)</td>
<td>3.6 (1.0) 4.0 (1.0) 4.0 (0.7)</td>
</tr>
<tr>
<td>3 years (n=10)</td>
<td>4.1 (0.6) 3.9 (0.6) 3.9 (0.7)</td>
<td>3.8 (0.7) 4.1 (0.6) 3.9 (1.0)</td>
</tr>
<tr>
<td>4 years (n=6)</td>
<td>4.1 (0.5) 4.1 (0.4) 4.0 (0.6)</td>
<td>3.8 (0.5) 4.0 (0.6) 4.1 (0.5)</td>
</tr>
<tr>
<td>All (n=36)</td>
<td>4.1 (0.6) 3.9 (0.6) 3.9 (0.7)</td>
<td>3.7 (0.7) 4.0 (0.7) 3.9 (0.8)</td>
</tr>
</tbody>
</table>

The lowest items were #21, “I know when each teaching technique I use will be most effective (conditional knowledge)” (M=3.2, SD=0.7); #24, “I ask myself if I have considered all possible techniques after teaching a point” (evaluation) (M=3.4, SD=0.9); and #10, “I set my specific teaching goals before I start teaching” (planning) (M=3.5,
The mode of almost all items was 4, except item #21, which was 3. Accordingly, first- and second-year teachers scored item #21 lower (M=2.7) than fifth-year teachers (M=3.5).

Overall, on a scale of 1 (disagree) to 5 (strongly agree), the survey-takers (n=36) scored a mean of 3.9 (SD=0.3) on the whole instrument. In terms of knowledge of metacognition (Table 4.2), their declarative knowledge seemed steady from teachers with 0 to 4 years of experience, with a mean of 4.1 in almost all the groups. Procedural knowledge slightly increased from Year 0 (M=3.8) to Year 4 (M=4.1); conditional knowledge also slightly increased from Year 0 (M=3.8, SD=1.0) to Year 4 (M=4.0, SD=0.6). The variability (i.e., standard deviation) of teachers’ answers decreased slightly in almost all indicators from Year 1 to Year 4. This could mean that their declarative knowledge about metacognition did not increase over time, but years of experience helped them better understand how and when to use it. However, none of these changes were statistically significant.

In terms of metacognitive regulation, the lowest indicator was planning (M=3.7, SD=0.7). As in the knowledge of metacognition, years of experience seemed to have a slight influence on scores, with higher means in Year 4 than Year 0. Thus, teachers can plan, monitor, and evaluate their practices somewhat better after four years (and with less variability) than teachers with no experience. However, I needed more evidence to support this evidence. I concluded, then, that during the first five years of teaching, participants’ knowledge of metacognition might remain almost the same or slightly increased.
Next, what variables could affect teachers’ metacognitive awareness? To answer this question, I first checked the internal reliability or consistency of the instrument. I used Cronback’s alpha for this purpose, obtaining a value of 0.808. As a rule of thumb, values in this test between 0.9 and 0.8 are considered excellent. Therefore, the instrument offered excellent reliability and allowed me to use the MAIT average in the linear regression analysis. I also conducted a diagnostic analysis to confirm that the data met the assumptions for the linear regression (Appendix M).

After conducting a linear regression of years of experience on metacognitive awareness (MAIT survey results), I obtained a positive relationship between these variables, $R = 0.187$. This means that as years of experience increased, the MAIT average scores increased as well (Figure 4.1), concurring with the hypothesis that with more years of experience teachers have more metacognitive awareness. The model for this sample was MAIT average $= 3.853 + 0.041$ (years of experience). This means that the intersect
(0 years of experience) was 3.853, and this value increased 0.041 every year. However, due to the small sample size, this correlation was not statistically significant: \( p = 0.274, 95\% \) (Table 4.3). That is, there is an increase in the participants’ knowledge of metacognition after years of teaching experience, but it is not statistically significant.

Table 4.3

<table>
<thead>
<tr>
<th>Model</th>
<th>Sum of squares</th>
<th>Df</th>
<th>Mean square</th>
<th>F</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>0.098</td>
<td>1</td>
<td>0.098</td>
<td>1.239</td>
<td>0.274</td>
</tr>
<tr>
<td>Residual</td>
<td>2.682</td>
<td>34</td>
<td>0.079</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2.780</td>
<td>35</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Dependent variable: MAIT average; predictors (constant): years of experience.

I also tested other variables that could potentially have a correlation with the MAIT averages, such as participants’ age, school socioeconomic status, program, gender, school level, and number of courses taught this year (Table 4.4). I present these descriptive statistics in Appendix N.

Table 4.4

| Regression Table: Teaching Experience on Metacognitive Awareness (MAIT Average) |
|-------------------------------|-----------------|-----------------|----------|
| Model                         | B               | Standard error  | \( \beta \) |
| (Constant)                    | 3.679           | 0.179           |          |
| Experience (years)            | 0.049           | 0.045           | 0.227    |
| School SES (%FRL)             | 0.001           | 0.002           | 0.046    |
| Program (1=UG; 0=MAT)         | 0.141           | 0.124           | 0.243    |
| Gender (1=male; 0=female)     | 0.035           | 0.102           | 0.062    |
| Group age (0=<25; 1=25-30; 2=>31) | 0.012       | 0.088           | 0.032    |
| Number of courses             | 0.028           | 0.051           | 0.101    |

The multiple linear regression was not significant (\( p=0.788 > \alpha = 0.05 \)) (Table 4.5), and none of the predictors listed on Table 4.5 were significant. This could possibly be a result of the limited sample size. That said, using \( \beta \) as a standardized value for the
importance of the predictors in a model, the potentially relatively important predictors (i.e., with higher $\beta$) in a larger sample size could include participants’ years of experience ($\beta=0.227$) and TEP ($\beta=0.243$).

Table 4.5

<table>
<thead>
<tr>
<th>Model</th>
<th>Sum of squares</th>
<th>Df</th>
<th>Mean square</th>
<th>F</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>0.270</td>
<td>6</td>
<td>0.045</td>
<td>0.521</td>
<td>0.788</td>
</tr>
<tr>
<td>Residual</td>
<td>2.509</td>
<td>29</td>
<td>0.087</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2.780</td>
<td>35</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Dependent variable: MAIT average; Predictors: (Constant), Number of courses, EXPERIENCE (years), SCHOOL SES (%FRL), GENDER (1=Male; 0=Female), PROGRAM (0=master; 1=undergraduate), GROUP AGE (0=<$25; 1=25-30; 2=>31)

In sum, I did not find a meaningful relationship between years of experience and teachers’ metacognitive awareness. Although not statistically significant, I found that the mean of metacognitive awareness showed a stable and slight growth when teachers had more years of experience. This means that survey-takers’ knowledge of metacognition increased as they gained more teaching experience, but this increment was not significant. A larger comparative sample between teachers prepared through two different teacher education programs would most likely help strengthen this correlation. The relatively important predictors of MAIT averages were years of experience and participants’ TEP; however, these were not significant either.

The second sub-question was: What is participants’ knowledge of metacognition as an element for science teaching? To address this question, I conducted semi-structured interviews with fifteen participants and used protocol coding to group their definitions of metacognition, reflection, and self-regulation. I then used open, focused, and in vivo coding to identify participants’ ideas related to metacognition.
I began by asking them what that thought counted as metacognition. Often, participants provided the traditional definition. For example, two teachers defined metacognition as the following:

*Metacognition is like thinking about the way you think. Like analyzing the way... analyzing your thought process, I believe.* (Emma’s interview, line 72)

*Um... metacognition, I would say it's just like thinking about... like thinking about, being self-aware, thinking about your own thinking process is kind of like what I think metacognition is.* (Kate interview, line 112)

I first tallied the words that participants used most often to define metacognition. The most frequent word was “thinking,” with 93% percent of teachers mentioning it. This was followed by “how,” mentioned by 60% of participants, and “reflection” and “learning,” mentioned by 46%. After that, the five words most frequently mentioned were “thinking,” “how,” “think,” “learning,” and “reflection” (Appendix O). (The word “know” was often used, not in the context of knowledge, but as an expression: “you know” or “I don’t know.”) The most common definition was “thinking how to think or reflect about learning” (Figure 4.2), as teachers often related metacognition to thinking and learning.

I then asked teachers how they understood thinking or reflecting about learning in the context of a science classroom. I also included questions about their understanding of reflection, self-regulation, scientific thinking, and the nature of science. The participants’ understanding of all these terms can be consulted in Appendix P, while the most common ideas about “metacognition,” “reflection,” and “self-regulation” are listed in Appendix Q.
Figure 4. Words used to define metacognition. The most common word was “thinking,” followed by “how,” “think,” “learning,” and “know.”

My analysis revealed that themes related to participants’ understanding of metacognition, according to the frequency in which they mentioned them, included the following: (a) metacognition is thinking about learning and thinking as scientists; (b) metacognition is reflecting; (c) metacognition is self-evaluation and improvement; (d) metacognition is “taking one step further”; and (e) metacognition is making connections. I present the frequency tally of each of these ideas in Figure 4.3.
Metacognition is Thinking about Learning and Thinking as Scientists

When I asked participants to explain what metacognition or thinking about thinking meant for them, they often related it to learning (66%) and to scientific practices or thinking as a scientist (73%) (Table 4.6). I explain each relation below.

Thinking about learning. As seen in the word count, “thinking” was the most common idea related with metacognition. The next most common noun was “learning.” Consider, for example, the following excerpts from teachers’ original definitions:

Metacognition. That’s a good one. Thinking about your own thinking. And, thinking, you know... trying to analyze your thinking. And, you’re learning. [It] tells about like being self-aware of thinking, of your learning. At least, that’s what I learned. (David’s interview, line 114)
Yep, so metacognition is thinking about one’s own thinking. So, realizing what you know and what you don’t know, what you’d like to know more on or connecting to past experiences. I use that in my classroom when I do reflections after we do labs, kind of like a conclusion but a little bit different in the fact that it’s more of a conclusion on what they thought about and what they think about kind of what they have learned, in that kind of regard. (Mary interview, line 182)

In these definitions, participants connected metacognition with learning. For instance, David used the word “learning” each time he mentioned thinking about thinking. Mary mentioned learning as part of a conclusion in a lab activity, and Kate explained metacognition as a reflection on learning.

Some participants also found a connection between metacognition and learning for life. For example, Emma tried to expand her definition, explaining how metacognition played a role in her science classroom:

To get your students to really learn about science, which is actually very important because if they can’t think scientifically then when they grow up they are going to follow everything blindly and not question society or themselves or come with their own conclusions about life. So, they have to learn how to think scientifically or to learn other things scientifically. They have to think about the way they’re thinking, metacognitively. (Emma interview, line 91)

During her explanation, Emma described metacognition as necessary for coming up with conclusions, not only about a lab practice but also about life.
Table 4.6

Participants’ Ideas about Metacognition as Thinking about Learning and Thinking as Scientists

<table>
<thead>
<tr>
<th>Participants’ ideas</th>
<th>Thinking about learning (10)</th>
<th>Theme (frequency)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Using it for teaching (2), independent learners (2), learning style, long-life learners</td>
<td>Recognizing problems (4), coming up with hypothesis (3), reflecting on hypothesis (3), coming up with experiment (3), testing one variable, making predictions, verifying validity of results, identifying bias (2), answering why (4), coming up with conclusions (3), thinking how you draw conclusions (5), understanding of science</td>
</tr>
</tbody>
</table>

Confusion explaining metacognition. Not many participants identified metacognition with independent or lifelong learning. Emma explained metacognition as learning how to develop critical thinking, question society, and not follow everything “blindly.” She is an example of identifying metacognition not as of learning, but for learning, as a tool to develop lifelong and independent learners. Henry and Jean also identified metacognition with helping students use self-regulation and teaching them how to learn. However, the idea of independent learning did not come up often during these interviews. In fact, participants related independent or ownership of learning more with the term self-regulation or self-control.

Thinking as a scientist. Often participants identified metacognition as an aspect of science learning. They frequently used examples of science and engineering practices to explain how metacognition related to thinking and learning about science. This led me to the term scientific thinking, although participants did not use that language or were not familiar with it, preferring thinking like a scientist. Next, I briefly explored how they described learning higher-order thinking skills related to science and engineering practices. Consider, for example, the following excerpts:
I say like, “let’s think about this like a scientist would or let’s use science thinking when we talk about this.” (Betty interview, line 160)

I try to get kids to understand science is a process of trying to, it's a question and starts with... trying to answer questions and collect data that would help us to answer questions so that’s how I use kinda the think as a scientist. (Matt interview, line 84)

In addition to think like a scientist, which was the most common term teachers used to describe the development of thinking skills using science and engineering practices, participants also mentioned “scientific method” (4), “inquiry” (3), “scientific process,” “critical thinking,” “experimentation,” and “scientific thinking.” Throughout the rest of this discussion, I will use “thinking as a scientist” when teachers mention the development of thinking skills after or during the use of scientific practices.

Teachers also used examples of scientific and engineering practices to explain how they understood and applied metacognition in their classrooms, although this concept was not always clear. In general, teachers seemed to understand the role of metacognition as awareness of how to come up with a problem, hypothesis, experiment, or conclusion. For example, Steve explained it this way:

Um... I was thinking on it, at the very bones of it... because... ah, ah... all of the science should be through this process of identifying the problem, you know, how can I test it or what, what could I figure out by testing it. Um... so being aware of just the process... of you know testing only one variable at the time, and all of that, it thinks, tides into... your learning process and rethinking how you came...
about that. Um... you know, saying an experiment goes wrong and you think, what did I do to get there... (Steve interview, line 24)

Here Steve recognized metacognition as thinking about the process of an experiment, testing variables, and identifying problems during experimentation.

Emma and Mary also found connections between metacognition and thinking as scientists when they discussed analyzing conclusions after a lab activity. Emma described metacognition as students’ awareness of how they came up with their conclusions: “I think it’s just like being aware of how you draw conclusions and um... any biases you may have or maybe like how you learn things and just... I guess it’s just being aware of your thought process and am... using that... never mind... I don’t know” (Emma interview, line 74). In this excerpt, it is not clear that she is referring to scientific practices. But later, in line 76, Emma explained: “I think that so if you have them write it down obviously. You can let them write down their thoughts on paper about what they’ve thought in the lab or how they concluded something and then you could analyze that. Actually yeah... that would be interesting for me to actually analyze that.” Emma commented that metacognition could be related with understanding how to come up with conclusions and the identification of bias. However, it seemed that she was not using metacognition for that purpose in her classroom, instead describing it as something interesting to do in the future.

Elsa also explained metacognition as thinking like a scientist, describing students as evaluating procedures, looking at results, or identifying bias while they read a scientific paper. As she explained:
Like if you **came up with a procedure, thinking about “did this really work?”** when you **look at your results** and if you’re recording what you thought you were recording or “is this working?” So just kind of, I guess, **recognizing problems, recognizing maybe bias in a scientific paper,** stuff like that to where you can look at something and see it beyond just the surface and kind of understand it better and be able to solve a problem or recognize that there’s an issue with something in the first place. (Elsa interview, line 31)

Two teachers described metacognition as identifying bias in student writing (Emma) or reading (Elsa), coming closest to the epistemological dimension of metacognition.

**Confusion explaining metacognition.** It was a common understanding among participants that metacognition was related to scientific practices and thinking as a scientist. However, at least 47% recognized that they did not have a clear idea of how to enact metacognition or explicitly said they were not using it.

In short, participants described metacognition as an awareness of learning and used science and engineering practices to explain how metacognition helps students think as scientists. However, they did not seem to be using metacognition frequently. Furthermore, only two teachers invoked the epistemological aspects of metacognition, mentioning the identification of bias in writing or reading scientific ideas. A few teachers also explained metacognition as thinking about actions, such as working on a lesson plan or teaching. Additional thinking about actions occurred when teachers described metacognition as reflecting, the next common idea.
b. Metacognition is Reflecting

Participants made a strong connection between reflection and metacognition. Some thought of the concepts as synonymous, while others described reflection as a more “comfortable” or useful term. They also used reflection to explain metacognition. For instance, when I asked Matt to clarify what “thinking about thinking” was, he explained:

“I think just reflecting, I think when I see this is... just reflecting and having an understanding of, you know... what works well and what doesn't. Because I think kinda what I think, when I see metacognition” (Matt interview, line 100). Like Matt, most other participants used the term “reflection” to describe metacognition:

And so, metacognition is... is like reflecting on the way that you think. Um... and so looking, so being metacognitive about my teaching would be looking at how or thinking about how I've, how I teach and how I can improve on my teaching.

(Steve interview, line 67)

I don’t know if I would’ve heard it. You know. I, is more turn as reflection or something like that so. (Henry interview, line 28)

The way I was always taught was that metacognition is thinking about your thinking. Just, just a deeper reflection, I guess. Kind of documenting, documenting your thinking and then keeping it and then looking, going back to it later and thinking about that. (Gina’s interview, line 101)

In these excerpts, participants related metacognition with reflection about learning, thinking, development, or what went wrong and how to make it better. Steve
explained that reflection and metacognition go “hand in hand” (Steve interview, line 81), while Gina explained metacognition not just as reflection, but as a “deeper reflection.” For participants, the concept of reflection seemed easier, more common, or more effective to use with students. As Kate explained, “Oh, reflection is probably a better word, I guess for kids, I would use like reflect on, reflect on what you learned or something like that” (Kate interview, line 118). Reflection seemed to be an easier term for students to understand.

Lucy mentioned that reflection was related with actions, but also with learning and thinking. She said “Um... yeah, I think so because I think reflection is a way that you can kinda sit and think about what you've learned and what you've done and... think about other questions you have” (Lucy interview, line 86). Like Lucy, at least 53% of participants related reflection with actions. Nevertheless, when I asked participants to explain their understanding of the word reflection, they used almost the same ideas to explain metacognition (Appendix R). The most common similar idea was thinking about learning, as in Lucy’s last excerpt.

In sum, some participants understood that metacognition and reflection are related but not synonymous concepts. Participants believed that both were related to thinking about learning. Frequently, teachers used reflection to assess learning and performance in the science classroom. I next describe how participants connected metacognition with assessment and improvement.

c. Metacognition is Self-Evaluation and Improvement

The next idea participants mentioned was how metacognition was related to self-evaluation for improvement. These participants recognized metacognition as a tool to
improve their teaching practice through thinking about what worked well and what went wrong (Table 4.7).

For example, Matt explained: “I think just reflecting, I think when I see this is... just reflecting and having an understanding of, you know... what works well and what doesn’t. Because I think kinda what I think, when I see metacognition” (Matt interview, line 101). Matt perceived metacognition as his internal process of understanding what he did well or less well. Teachers were aware that metacognition was needed as part of their practice, especially to improve.

Table 4.7

<table>
<thead>
<tr>
<th>Participants’ Ideas about Metacognition as Self-evaluation and Improvement.</th>
<th>Themes (frequency)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Self-evaluation (11)</td>
</tr>
<tr>
<td>Assessing (6), thinking about what went well or wrong (5) after labs or problems, self-evaluating (2), peer-evaluating, what I do/don’t know, what needs to change</td>
<td>Teaching, lessons, behaviors (students)</td>
</tr>
</tbody>
</table>

Kate also explained metacognition as a self-evaluation: “I guess like how do I do it, a lot of times just um... I guess once again is like the self-reflection for me, like what I want right, what I did right, like how do I need to change my classroom it's kind of my metacognition. How do I like, you know, basically, how I evaluate myself, it's like thinking about my thinking or like I thought this would work and it didn't work so I have to go back and reevaluate that” (Kate interview, line 116). She explained metacognition as thinking about what she did correctly and what she needed to change, using the phrase “self-reflection for me.” Again, her concept of metacognition was related with an internal evaluation of teacher performance. However, she also ended by
saying that metacognition is not just thinking about what went wrong, but also going back to “reevaluate.” This was a way of understanding metacognition shared by several participants.

Gina also referenced the idea of thinking about what went wrong for improvement, for herself as well as for students. She explained: “you could use it yourself as a teacher to improve your, your lessons and you can also have your students use it to where you know, they like self-evaluate or maybe they evaluate each other and then they evaluate themselves in a group project or something. Just having them think about their own work” (Gina’s interview, line 103). Here Gina related metacognition with two important elements of assessment after a group project: self-assessment and peer assessment. Interestingly, Gina was one of the few participants who considered metacognition a social activity. She also recognized the potential of metacognition to improve her lessons.

Confusion explaining metacognition. In general, teachers understood metacognition as an individual and internal activity. For example, David and Kate used the word “self-awareness,” while Gina used “self-evaluation.” Participants clearly did not consider collaboration as enhancing metacognitive processes. Moreover, they did not often mention planning or monitoring as part of metacognition.

d. Metacognition as “Getting One Step Further”

For some participants, metacognition implied a “double cycle” of thinking. To explain this, I called the next section “taking it one step further,” based on Gina’s words: “Metacognition is more like ‘I felt like, like it went poorly and I think this is what I could do differently or I think this specific student, I think this would be a good strategy for the
Student based on something that worked well for me last semester, ’just taking it kind of one step further” (Gina interview, line 119). Gina provided examples of strategies she might use to evaluate her lessons or explain metacognition to students. She ended by saying that metacognition was taking it a step further. This term is fitting because metacognition entails going beyond, engaging in a double cycle of learning. However, for some participants this seemed more like an extra step than a deeper one.

Jean used the expression “go beyond” when she explained metacognition: “Yea, you know... I think once I reach that step where they are actually doing thinking in the first place then I can go beyond and have them think about how they learned things, and um... once they kind of start thinking about what metacognition is then they can rather um... learn things for themselves and really take [inaudible] on their own learning. If that makes sense” (Jean interview, line 36). Here she attempted to describe metacognition as going beyond, thinking about how students learn things for themselves. Later Jean explained that she found it difficult to use metacognition with students because she wanted to them to think at an initial level. Encouraging them to think again about what they thought in the first place was challenging for her.

Confusion explaining metacognition. For these participants, the “double cycle” of thinking often indicated that metacognition was something complicated or repetitive. They commonly conceived of metacognition as “how to come up with certain things,” to use Jean’s words (line 6)—that is, to think about something and then think about how they thought of it. This understanding was a literal connection to the traditional definition of “thinking about thinking.” For example, Kate used the word “re-evaluate” to explain
that metacognition was the awareness of how she evaluated her lessons, or how students assessed a hypothesis.

e. **Metacognition is Making Connections**

For participants, metacognition also involved making connections with other courses, prior knowledge, students’ experiences, the world, or the application of a concept in new situations.

Henry used the word “connections” when explaining how he used metacognition in his classroom: “I also wanted to see that science is very connected, so we’ve been talking a lot about that and... um... you know... I think that is a good bridge, the physiology connection and the physics connection... um... the my... I... I’ve mostly tried to point out things they’ve learned in other classes” (Henry interview, line 40). Henry used the metonymy of a “good bridge” to explain how metacognition can help students build connections between courses.

Likewise, Lucy used the term “connections,” but related this more to the concept of scaffolding new knowledge. Metacognition, in her view, helps students make sense of what they learn and their classroom activities. She explained it this way: “So, you can have all of, you know, be busy doing all this stuff, all these discussions and all these activities and stuff but I feel like if I don’t give them time to make sense of it by themselves... um... then they’re not making those full connections that they could with them... I guess, hopefully I mean...” (Lucy interview, line 90). Lucy noted that after learning activities it was important to give students time to make the connections needed to understand the goal of the activity.
Metacognition as a way to build connections was not just related with learning goals, but also with teachers’ instructional decisions. David described metacognition as explaining his reasons behind his decisions. As he put it, “Usually, I am informing kids and tell them why would you do things in a certain way and what would you do and, and you know... informing above my... logical decisions and say ‘oh, we’re doing this because you know, I’m...’” (David interview, line 118). Gina described it this way: “like having kids think about their own skills and stuff. I, I wish I had, you can use it you’re good, I guess I wish I had students think about that more, like, ‘why are we actually doing this?’” (Gina interview, line 101). David said he informed students, while Gina reflected on how to help students think about why they were studying certain topics. She wanted them to understand the purpose of learning goals to develop “skills and stuff.”

Thus, for these participants, metacognition involved not only thinking about how someone came up with an idea, but also why—the reasoning behind their ideas, decisions, and teaching goals. For instance, in Henry’s words: “Ah...I think that, that comes with questioning techniques, I guess. Uh, to where... you... yes... say it, say students have troubles with a problem. And... my first question is: ‘okay, what have you done? So, ‘what make you think that? Why were you thinking that or where did that go?’ And so, making them aware of how they got to that point. I think it’s a big step” (Henry interview, line 18). Henry described questioning techniques to help students make connections about why they gave an answer and how they arrived at it.

**Confusion explaining metacognition.** Participants sometimes identified the use of “why” and “how” to explain metacognition. However, they did not link these questions with scientific practices or the epistemology of science. They understood
metacognition as using scientific concepts or explaining instructional decisions, but they rarely mentioned why or how to analyze the validity of data, reflect on an experiment, or assess their arguments based on evidence, for instance.

Other Ideas Related to Metacognition

Participants used other ideas such as “awareness” and “talking about feelings,” including asking students how they felt, but these were not extensively mentioned. Some teachers used “analyzing,” “reasoning,” or “thought process” as an alternative to “thinking.” Other ideas not as frequently mentioned were related to metacognition and thinking about actions and goals. For example, Henry connected metacognition with working on a lesson plan, while Frank, Gina, and Steve mentioned it as necessary for improving their teaching. However, participants rarely discussed setting goals for themselves, which aligns with the results obtained using the MAIT survey. Teachers ultimately did not seem to connect the use of goals with metacognition.

Confusion explaining metacognition. Participants often used expressions such as “I don’t know,” “maybe I have this wrong,” “I guess,” “if that makes sense,” “never mind,” “something like that,” “at least, that’s what I learned,” or “yeah… that’s what I think” to explain metacognition. These expressions indicated that they were unsure or did not feel confident in their explanations. Paula, the only first-year teacher who agreed to participate in the study, admitted that she never understood the term, even after her TEP: “I’ve heard it but honestly even when I was in the grad program I never really understood it, to be honest with you. So, I don’t know. It’s just like, bringing back previous knowledge. I really don’t know what it means” (Paula interview, line 135). Even when Paula recognized she did not understand the term “metacognition,” this did not
mean that she was not using it. She could relate metacognition to “*bringing back previous knowledge*” and described using reflective practices in her classroom to teach science.

**Summary of Findings Related to Research Question #1**

Study findings indicated that participants were aware of their knowledge of metacognition and that this knowledge increased slightly with teaching experience, based on the MAIT survey results. However, this increment was not significant. Therefore, what teachers learned about metacognition from their TEP informed their first years in the classroom.

Table 4.8

*Participants’ Understandings and Misconceptions of Metacognition*

<table>
<thead>
<tr>
<th>Theme</th>
<th>Understanding</th>
<th>Misconception</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning and thinking as a scientist</td>
<td>Metacognition is needed for learning and using scientific practices.</td>
<td>Independent learning is related with self-regulation and classroom management.</td>
</tr>
<tr>
<td>Reflection</td>
<td>Reflection is a simpler term than metacognition.</td>
<td>Metacognition is an internal and individual process.</td>
</tr>
<tr>
<td>Self-evaluation and improvement</td>
<td>Metacognition is about looking back to improve teaching and learning.</td>
<td>Planning and monitoring are not part of metacognition.</td>
</tr>
<tr>
<td>“Getting one step further”</td>
<td>Metacognition is a double thinking cycle.</td>
<td>Metacognition is complicated. It means to think about how you came up with an idea.</td>
</tr>
<tr>
<td>Making connections.</td>
<td>Metacognition is about why and how you came up with an idea.</td>
<td>It is to answer how and why about instructional decisions or answers related with scientific concepts.</td>
</tr>
<tr>
<td>Other ideas</td>
<td>Metacognition is about feelings, analysis, and reasoning.</td>
<td>Not using metacognition in the science classroom.</td>
</tr>
</tbody>
</table>
Teachers who graduated from the Master’s program had a slightly better awareness of metacognition than those coming from the undergraduate program. Certain experiences in the classroom might have helped them make better decisions and use more effective strategies. Nonetheless, their knowledge of metacognition did not increase substantially during their first years as teachers, especially their theories and beliefs (declarative knowledge) about it.

Participants typically identified the traditional definition of metacognition: thinking about thinking and its relationship with learning. However, they rarely mentioned independent learning, an idea they related more with self-regulation than with metacognition. They also understood metacognition as thinking like a scientist, reflection, self-evaluation and improvement, “getting one step further,” and making connections. However, they held some misconceptions about it (Table 4.8) and often recognized they were not using metacognition to teach science.

**Research Question #2:**

*What are the Common Instructional Practices of Metacognition (Metacognitive Teaching) Used by Beginning Science Teachers?*

After acquiring a better understanding of teachers’ knowledge of metacognition, my next step was to analyze how they used this construct in the classroom, a question I asked in my interviews. I could often corroborate these self-reported practices with the classroom observations I was conducting in the larger research study. In some cases, participants described practices they had employed only once or twice. Furthermore, some teachers realized they were not using metacognitive teaching frequently or at all.
On the other hand, sometimes participants were using metacognitive teaching without being aware of it.

As a result, I decided not only to solicit teachers’ descriptions of metacognitive practices, but also to ask how they used reflection, self-regulation, thinking as scientists, and the nature of science (NOS) in their classrooms. Thinking as scientists and NOS practices could help me understand how they were engaging with the epistemological aspect of metacognition, while asking about their teaching practices of metacognition, reflection, and self-regulation could indicate how they were engaging the psychological aspect. I list the teachers’ answers in Figure 4.4. After reading and compiling the practices they described, I looked for patterns and reorganized the data by category. I ultimately grouped the responses into three levels based on the purpose, outcome, and mode of the teaching practice described.

Teachers used practices of metacognition for three general purposes: (a) for classroom management, using common sense and reflection about students’ behaviors; (b) for learning accountability, asking students to sum up their learning after a lesson or for a test; and (c) for promoting thinking as scientists after using science and engineering practices (Figure 4.4). For all of these purposes, participants described either formal and informal student outcomes or learning products. For example, informal metacognitive practices occurred when teachers issued direct instructions to make students think, such as explaining their pedagogical decisions. In these cases, teachers did not ask for a concrete product or outcome of students’ reflection for further analysis. In other words, they did not collect evidence of the students’ thinking. On the other hand, formal
metacognitive teaching occurs when teachers describe questioning techniques and ask students to write down their answers as part of a worksheet or a lab report.

**Figure 4.4** Metacognitive teaching. Participants’ mentioned teaching practices related with metacognition in three groups: classroom management and students’ behaviors, making learning accountable, and developing scientific thinking.

Additionally, teachers described different modes or ways of promoting reflection and metacognition among their students. One mode was a more teacher-centered model in which teachers described direct instruction, such as thinking out loud while explaining how to solve a problem or articulating an instructional decision. A second mode involved participants acting as facilitators, guiding students’ metacognition using questioning techniques. This might involve asking questions or giving students writing prompts to come up with a conclusion, whether oral or written. The third mode characterized metacognitive teaching as facilitating students’ generation of their own strategies, questions, or criteria for assessing their work.
When participants described teacher-centered practices as metacognitive teaching, regardless of their purpose or evidence of students’ thinking, I categorized this as teacher-assisted learning. On the other hand, when teachers described facilitating metacognition by helping students attain an awareness of their learning and thinking in formal settings, I characterized this as contributing to the developing of independent learners. Finally, I considered whether the practice incorporated collaboration and group work or whether the reflection was done individually.

Using Figure 4.4, I considered practices oriented to the right side of the diagram as more sophisticated (complex, implicated higher-order thinking, provided greater opportunities for students, or supported the development of independent learners and scientific literacy) than those oriented to the left side of the diagram. I realized that sometimes one strategy could include two or more purposes. However, I found the diagram useful for better understanding metacognitive teaching practices, and will thus describe these based on their level of sophistication. The diagram begins with practices related to direct instruction or conversations about metacognition; moves into practices related to questioning, assessment, writing, and solving problems; and ends with facilitating students’ generation of their own questions (Figure 4.5).

As illustrated below, teachers often reported that they were not using metacognitive teaching practices:

_I: Do you, do you use it [metacognition], Gina?_

_R: Not as much as I would like._ (Gina interview, lines 104-105)
I don't do it with my students, I probably should. But, I know that I’m... digging more about... how I can get them to certain areas and so, it's then metacognition for me, more than I had then for my students. (Pam interview, line 89)

Right, to think about their thinking... and I think last so with that, and it’s not because I don’t want to, it’s just I’m just trying to get them to think at all. (Jean interview, line 32)

Over the course of the interviews, each participant described in one way or another how they were using metacognition or reflection, even when they were not completely aware of it. Perhaps this was because their metacognitive teaching practices were not aligned with their own understanding of and experiences with metacognition. Figure 4.5 describes the most common metacognitive teaching practices described by participants.

**Oral Conversations**

The first group of metacognitive teaching practices was based on verbal conversations or direct instruction. For example, third-year teacher David used the word “informing” to describe how he communicated his instructional decisions to students as part of metacognitive teaching:

Usually I am doing, informing kids and tell them why would you do things in certain way and what would you do and, and you know... informing above my... logical decisions and say “oh, we’re doing this because, you know, I'm...” If I could even, even the... discussion about having cell phones in the classroom or calling your cellphone out and what research says about that and it's not like I
Figure 4.5 Practices of metacognition. The number represents the tally of participants who mentioned the practice. Practices in the right side are considered to be more complex or oriented to independent learning than those on the left side.
am a control freak and I don't want you to use it. There are reasons for things.

And, you know, and I like to inform kids when I make decisions and tell them why I think... I think it is just fair, “this is why.” (David interview, line 126)

David shared this example of cell phones in class to explain how he used metacognition, including discussing the reasons behind a rule or providing research so students could understand it. His purpose for using metacognition in this case was classroom management; the outcome was informal (he did not mention how he verified if the students understood his reasons); and the mode was direct instruction.

Participants also related problem-solving and thinking aloud with oral conversation. For example, Steve, a third-year physical science teacher, described repeating the same procedures and talking aloud about how to solve a problem. By using this metacognitive practice, he expected students would learn to use the same procedure: “And really making them aware of problem solving skills. So, every time I try to use the same ah… sentence of ‘okay, what does the problem give us, what is in the problem that we know’. And, by just repetitively doing that hopefully they’re thinking ‘oh, any time that I solve the problem I need to think this way’... hopefully” (Steve interview, line 36). Here he described his teaching as repeating the same sentences during a procedure. His purpose was helping students learn how to solve problems, which involves accountability for learning, but there was not an outcome mentioned. He used the expression “hopefully” because he expected students to learn these steps, but he did not relate it with any assessment product. Finally, the mode is direct instruction, as he was the one repeating the sentences.
I called these practices “oral conversations” because teachers often used the expressions “have a conversation” or “talk” with students about certain issues related to reflection, metacognition, or the nature of science. However, sometimes participants used the verb “to talk” to describe telling students (i.e., direct instruction) about connections they could make, evaluations of their behavior, or how science works. For example, as Jean said in the following excerpt:

Um... so, even today we’re talking about cells and how... um... how over the course of 200 years it took them [the scientists] that long to come up with the cell theory and saying... all living things are made of cells and all cells come from other cells and that [inaudible] life... so, I try to like really talk about that and how it is a building process and not just a building process, it’s what scientists have done in the past but also we are doing now and that again we just take some stuff for granted and some of the knowledge that we have for granted.

(Jean interview, line 94)

In this excerpt, Jean described telling students how scientists come up with theories and how science develops through time. The purpose of the practice she described was helping students think as scientists. The outcome was informal, since at most she might have heard some student comments if this were a whole group discussion, which she did not disclose. The mode was direct instruction.

Overall, teachers rarely described using the nature of science in their classes. David, although enthusiastic about the concept, said that high school students were not cognitively ready to engage with it. Jean, the four-year teacher from the previous excerpt, tried to generate reflection about how science works. Even though her example was based
on direct instruction, it could still be a first step toward addressing the epistemology of science more frequently in the high school classroom.

**Oral Questioning**

The next group of metacognitive teaching practices involved teachers asking questions in order to generate reflection. Oral questioning and oral conversation are closely related. I considered oral questioning slightly more sophisticated, however, because questioning implies that students are thinking of answers. Conversely, teachers sometimes described asking questions and then giving the answers to students.

For example, Gina, described an episode when she was teaching students how to balance chemical equations:

*I guess an example would be yesterday we were **balancing equations in my physical science chemistry** class and we had, that’s kind of a **rougther group of students**, we have a lot of IEP’s, we kind of have a SPED portion of it and then we have another portion of it that’s kids who kind of failed regular chemistry. *A lot of times there’s **just some behavior issues** and stuff and one of the girls, she goes like, “**when am I ever gonna have to know how to balance equations ever in my life?”** and I was like “well,” I said, “I don’t care if you actually know how to balance equations” I said, “**but how did you react when you were balancing them?”** I said, “**did you, did it get tough and you just shut down or did you keep going when it was hard?”** I was like, “I don’t care if you know how to balance them it’s about the **problem solving skills**, and it’s about not giving up when it’s tough.”* (Gina interview, line 20)
Here Gina asked questions in order to generate reflection and metacognition, attempting to improve the student’s attitude toward the class and help her find outside meaning in the activity. The purpose of these metacognitive teaching practices could be related to behaviors and classroom management, although it could also be associated with accountability of learning if the learning objective involved problem-solving skills. The teacher clearly explained why they were balancing equations: to develop problem-solving skills. In other words, by asking those questions, it seemed she wanted to explain the reasons behind her instructional decisions. There was no outcome aside from the conversation, at least none mentioned, so I would categorize it as informal. The mode was questioning: the teacher asked questions to generate awareness among students. At the end, she also used direct instruction, “telling” the student her answer to the question.

Another example in this group would be Steve, a third-year physical science teacher. He explained how he used metacognitive teaching:

*I talk with them, one on one.* Yeah, *either in the hallway or back in the classroom or something.* And, *or if they’re not doing, a student is not doing well,* *they are not doing well in a class, in my class or they just bomb a test or something.* *I can ask them to be, to be reflective on their, on their understanding.* How do you think you’re doing in class? What do you think you can do better? What are some ways that you can improve your grade in this class? What are some things that you think that I could do to help you to do better in this class? (Steve interview, line 77)

In this example, Steve used questioning to reflect on students’ class performance. Although he used the result of a test to start a conversation, he did not mention whether
he asked students to generate a product during or after the reflection. Thus, there is likely no formal outcome. The mode is questioning, since he used questions to generate student reflection and listened to their answers.

Some teachers suggested questioning strategies for metacognitive teaching but did not have a clear idea of how to implement them. For example, Emma, a fourth-year middle school teacher, said: “I just tried to maybe give them some… prompts some questions. Maybe like, okay you know if you thought this then why or if you thought this then this means you conclude that correct. Some leading questions to get them start thinking about their thinking. I have to do that, probably” (Emma interview, line 101). Here, Emma related metacognitive practices with students thinking as scientists and with questioning strategies. Although she seemed unsure of how to employ these practices and might not have been using them at the time, she said that she needed to do so.

**Assessment**

Among these practices, and accordingly with participants’ understanding of metacognition, the most common practices for metacognitive teaching were those related with formative assessment or assessment for learning (Figure 4.3). Teachers also mentioned metacognition in relation to testing. As a result, I decided to group these practices to describe how teachers used metacognitive teaching in assessment practices during a science lesson. In fact, all participants mentioned assessment practices (formative or summative) when describing how they used metacognition or reflection in their classrooms.
A common practice for formative assessment was the use of learning summaries after a lesson (e.g., exit tickets) or questions related to what students learned the previous class (e.g., opening questions, “bell ringers,” etc.) as strategies to promote metacognition. For example, Steve explained: “You know, and so those things that you could do I think either by just having them share out loud where they're making those connections or by me asking them or having them write down... um... like in an exit ticket or something like that, where, you know, tell me one thing that you learned today in class, tell me one connection that you made or say one thing that you know now that you did not know before” (Steve interview, line 19). Steve mentioned the concept of metacognition as making connections and described how he asked students to write down those connections or learning after a lesson. The purpose of his last description was learning accountability. The outcome was formal, since students wrote the exit ticket and teacher could analyze their learning closely after the lesson. The mode was questioning, as the teacher posed questions for the students to answer after the lesson.

Kate used the term “bell ringers” to explain how she incorporated these learning summaries: “I guess like bell ringers and I sort of work like that, like they're [the students] reflecting on what they learned the day before and how well did they understand it” (Kate interview, line 120). She explained that she started her lessons by posing a question and asking students to recount what they learned from the previous class. They usually discussed the answers as whole group in order to make connections to past lessons and keep moving forward with activities for the day. The purpose of this practice was accountability for learning; the outcome was formal (as well as informal, if there was a discussion); and the mode was teacher questioning.
Elsa also used summaries. Elsa explained that not only after a lecture, but also at the middle and end of a lesson, she questioned students about their understanding of the topic and asked them to rate their confidence level.

*I think my kids have not heard that term but I do openers all the time and usually kind of middle and end of the unit one of their openers will be like thinking about where they are with things in the class, like do you understand what’s going on and can you access, how do you feel about what we’re learning, are there things I can do to help you with it or are there things that you maybe need to do or sometimes I’ll have them rate confidence and then what are you still struggling with and why.* (Elsa interview, line 122)

This connection between metacognition and feelings was not very common in my findings, but it is important nevertheless. Elsa’s experience represents another formal example of accountability for learning after teachers’ questioning.

Pam and Lucy explained formative assessment practices like asking students to use their thumbs up/down to rate their understanding after a topic. This is an example of how informal metacognitive practices provide teachers with the necessary information to make quick decisions during their instruction. Therefore, an informal practice is not necessarily a bad practice. Lucy also explained:

*For the formative assessment. So, sometimes at the end of the day I give them a writing prompt or I ask them you know with a specific question or ask them to summarize the day or write a reflection about the day”* (line 24).

*Yeah, so I think... in the classroom I think this is reflective in their science journals when I give them writing prompts or ask them to do reflections a lot in*
their science journals. So reflecting on the day, for example, we did a reflection on the Monarch tagging after we did that so... am, you know... just having them summarize and think about what did you learn about the day, what was interesting, what would you like to learn more about, what would you not understand. (Lucy interview, line 84)

Lucy used science journals to collect students’ reflections about their progress in their development of thinking as scientists. Her purpose in this activity, based on my diagram, was to develop students’ thinking as scientists using a formal tool, such as a science notebook or journal, through questions at the end of an inquiry activity. This mode of facilitating reflection and metacognition could be considered more sophisticated and complex than asking questions after a lecture. Lucy demonstrated a clear understanding of how to use metacognitive teaching as part of her science classroom. Her experience indicates that more sophisticated practices should push students into understanding the epistemology of science and becoming independent thinkers and learners.

Metacognitive teaching was also related with summative assessment, primarily described as a tool for self-evaluation after a test or quiz. For example, Betty, a fifth-year teacher (teaching out-of-field that year) explained how she used reflection in her classroom: “well I’m really good at self-reflection. But, then the kids, reflection maybe I’m not great at. But, I guess having kids write as much as you can, and ask them like, don’t let them just look at their grade and look at their test and throw it away or look at their quiz and like get rid of it. They need to really like see, you need to show them how to like think about things and what you’ve done and how to make it better” (Betty
Here Betty described the importance of formal metacognitive practices, asking students to think and write about their self-evaluation after a test or a quiz. Betty admirably demonstrates her awareness that sometimes, although this might seem obvious to teachers, students do not relate grades with learning. In fact, they might not think about their grades at all unless a teacher asks them to do so for a specific purpose. In this way, Betty used reflection with the intention to cultivate student accountability after a test. This is an example of formal accountability using teachers’ questions.

Henry, a third-year teacher, also mentioned using tests to develop students’ metacognitive awareness. He explained his metacognitive teaching practices as follows:

*So, one of the things is I do a lot my kids *redo all of their quizzes and tests*. And, *they have to come in, and they work, and they have to show their answers or so, their work*. And, *they can get half as many points they’ve missed… Obviously, if you get it wrong, and you just move on, you’re never going to figure it out why you got it wrong*. And so, *that is part of it. And, I hope you know, by allowing them to do that they have the motivation to come back in and learn it*.

(Henry interview, line 54)

Henry considered re-doing tests a metacognitive teaching practice. He expressed his understanding of this activity as contributing to students’ learning. How much this might promote awareness, connections, or self-evaluation of students’ learning is not clear in this excerpt. This was an informal accountability for learning. The mode of teaching strategy is not defined in this example. However, if the teacher did not
encourage reflection, there is no evidence that all students who re-took a test would reflect on or think about their learning and growth.

In sum, there was a clear connection between metacognitive teaching practices and formative assessment. Participants with different years of experience often mentioned learning summaries, exit tickets, opening questions, and science notebooks or journals as examples of how they used metacognition in their classrooms. Teachers frequently used these practices through tests, quizzes, and accountability of learning. This information could be utilized to inform teachers’ instruction as well as to make students aware of their learning. As my findings reveal, setting an intention to promote student reflection after a test is an important element of metacognitive teaching practice.

Writing Prompts or Questions

Writing prompts or questions can also be an effective strategy for metacognitive teaching. In the assessment section, I described how teachers posed questions at the beginning of a lesson or after a test to help students summarize their learning, self-assess, or connect previous learning with a new lesson. Nevertheless, I also want to illustrate specific metacognitive practices related to writing prompts that can help develop more sophisticated or complex metacognitive teaching.

I will start with Paula, the first-year teacher who recognized that she never understood metacognition. However, when I mentioned reflection to her, she was able to think of some teaching practices and described using them in her biology and physical science classroom. For example, she said: “And then, I also try to encourage reflection. I don't do it as much as I should but I have done it in the past where I do have students do reflection or lab reports where they have to write like a conclusion what did I learn,
what was the purpose of what we did, that kind of thing. Reflection, yes.” Here Paula described this metacognitive practice as formal (i.e., writing a conclusion), accountability for learning, and using teacher questions. However, this could also be related to the purpose of thinking as scientists if the lesson was inquiry-oriented and students came up with their own connections about the purpose of what they were exploring.

As another example, Lucy explained how she gave students templates or sentence starters to help them develop thinking skills, not only for metacognition, but also for summarizing, making inferences, or analysis in science journals. As she stated:

One of the things that they did with their science journals that kind of helps them with these different thinking skills is that I have a sheet that’s called "thinking stems" that we uh... printed out and put it in their journals so there's different categories so there's a category for analyzing and different category for observing, different category for summarizing and for um... observations I think there's... gosh... maybe six or eight different categories but anyways... it gives them kind of some sentence starters. So, this is kinda what it sounds when you're talking like a scientist or when you are analyzing or when you are summarizing, or when you're making an inference. It kinda helps jog their memory of what it sounds like or what it looks like in their writing to use some of those, those skills... um... and then... I think just practice, practice, practice. (Lucy interview, line 126)

In this excerpt, Lucy demonstrated a clear understanding of how to develop students’ thinking skills. She described the different skills and how she provided students with sentence starters to help them understand how to analyze or summarize information.
Therefore, writing prompts are an effective pedagogical strategy for teaching students thinking skills, including metacognition. However, the idea that teachers could not see students’ thinking was also common among some participants. For example, Gina explained that it was easier to be aware of physical skills (like throwing a softball) than thinking skills. Gina said that this might be because she could not see thinking skills directly. We might not observe thinking skills directly, but that is where the important learning outcomes take place. Students can demonstrate their thinking when they write a conclusion for a lab report, for instance.

Going back to Lucy’s excerpt, this could be an example of a formal, thinking as a scientist, written metacognitive strategy. I also considered it an exemplary practice and an effective example of how to promote thinking as a scientist in the classroom. Thankfully, she was not the only teacher who mentioned this kind of practice.

Other teachers, like Gina, understood the importance of writing prompts, even if she was not using them: “I just tried to maybe give them some… prompts, some questions. Maybe like, okay you know if you thought this then why or if you thought this then this means you conclude that correct. Some leading questions to get them to start thinking about their thinking. I have to do that, probably.” Gina recognized the importance of those leading questions to guide students’ thinking skills. When I asked her why she was not using them, she explained that as a second-year teacher she was focused on content and “still swimming above the water” (Gina interview, line 105). Participants considered writing prompts and practice important elements to help students develop higher-order thinking skills and metacognition.
Problem-Solving

Mathematical thinking and problem-solving are two important scientific practices for science teaching, especially for courses like physics or chemistry. Some participants related metacognitive teaching practices with problem-solving. For example, Betty explained:

*I have before like when they, okay, like let’s say, I have them do an assignment, and how about I make them show their work, and they mess up really bad on the problem, and “if you screwed up really bad on this problem, I want you to think about what you did wrong, and you know that you struggle in that area, and so you’re aware of it. And now you have to think about what you did wrong and look at what you did wrong and make sure that we can figure out how to do it right next time.” I tell them to be, I don’t use that word though, I tell them to be reflective and I don’t know if I’m even close to what you want, to what you’re actually even asking right now, but…* (Betty interview, line 170)

This was an example of an accountability learning strategy after teachers’ questions. Betty asked students to show their work by writing down their process for solving a problem, which helped them identify where they were struggling or what they did wrong. Because Betty said that she “asks them to think,” this appears to be an informal reflection without an outcome. Interestingly, Betty ended by mentioning that she called this practice “reflection” and was not sure if that answered my question about metacognitive teaching.

Elsa, a second-year chemistry teacher, also described asking students to find mistakes, which she called “making sense” of the numbers:
I guess, have to teach them a lot of the skills of “how do you recognize if your numbers are making sense,” and not telling them how to change their numbers, but like ‘how do you recognize experimental error’ and some of those things are usually built in to labs so like looking at your own numbers, referring back to those numbers and recognizing something went wrong is kind of a big thing, just knowing that there’s a problem in the first place. (Elsa interview, line 33)

Elsa’s excerpt was an example of the importance of modeling, thinking out loud in order to exemplify the sort of questions or observations students should be practicing. Elsa’s metacognitive teaching practice could be an informal, thinking as a scientist (based on the evaluative aspect), teacher questioning one. In a prior example, Henry was also solving problems thinking aloud. Modeling thinking or thinking aloud could be a useful strategy for metacognitive teaching, but it should not stop there. Teachers also need to provide students with opportunities to practice thinking on their own.

In sum, participants recognized metacognitive teaching in the practices of problem-solving, mathematical thinking, identifying mistakes, and making sense out of numbers. They mentioned thinking out loud and modeling problem-solving procedures as the most common strategies.

**Asking Students to Write Their Own Reflective Questions**

The most complex metacognitive teaching practice involved teachers facilitating opportunities for students to come up with their own reflective questions. For example, Mary described how every week or so, she asked students to write two sentences summarizing their learning and generate a few questions about what they would still like to know about the topic. This practice could be classified as formal (i.e., a written
learning outcome), thinking as a scientist (i.e., they complete a small research task related to the science content), and students’ ownership and self-regulation. This was one of the most complex and sophisticated practices that I found among the participants, and I will describe it in greater detail at the end of this chapter.

**Summary**

In conclusion, the most common metacognitive teaching practices teachers described were learning summaries before and after a lesson and formative assessment practices. Teachers often described accountability of learning as the most common purpose for using metacognitive teaching practices. This aligns with the definition of metacognition as self-evaluation employed by participants. More experienced teachers described a larger range of metacognitive teaching than first- and second-year teachers. In general, teachers recognized they were not using these practices as often as they could be. I will talk more about possible reasons for this realization in the next section of my study.

The metacognitive teaching practices described here were based on what participants self-reported. Some participants were honest and recognized that they did not use metacognition as often as they could, should, or wished to. In contrast, other participants, such as Frank, Lucy, and Mary, described metacognitive practices as a regular aspect of their science teaching.

I noticed at least three significant absences in the metacognitive teaching practices described. First, teachers did not relate metacognition with teaching students how to study or use learning strategies. This does not mean that teachers were not using these practices, but they did not mention them during the interview. The second notable
absence was metacognitive teaching as part of summative assessment, referring to when teachers use metacognition as part of their learning goals and factor it into students’ grades. Instead, teachers related metacognitive teaching with formative assessment or assessment for learning. They also viewed metacognitive teaching practices as useful for generating awareness about students’ learning or informing their instruction. How much they used this information to modify their instruction and make instructional decisions was not clear, as participants did not mention it and I did not ask. Furthermore, since my study was focused on metacognitive teaching practices and not on formative assessment, this line of inquiry was outside the project scope.

I understood that the main role of metacognitive teaching for these participants was related with learning. However, summative assessment and grades are an important part of secondary teaching that allow teachers to measure and report students’ learning. Teachers and students will invest time and effort in activities that generate a grade. As a result, most participants did not consider metacognition or reflection as part of their teaching goals.

The third significant absence was the use of group reflection or collaboration in teachers’ metacognitive practices. Usually participants described practices as individual reflection or thinking, or as students writing individually about their performance. This also aligns with teachers’ understanding of metacognition as an individual and sometimes internal activity.

For me, it was important to know, as part of this research question, *what elements do teachers believe could affect their instructional practices of metacognition (or metacognitive teaching) as part of science instruction?* During the interviews,
participants reflected about what they felt might help them use metacognitive teaching practices in their classrooms and what might limit or prevent them from using them. I included reflection, metacognition, and the nature of science in my questions to cover the two dimensions of metacognition (psychological and epistemological). After coding participants’ answers and reflections, I found the themes listed in Table 4.9. Next I will describe the factors teachers identified as either facilitating or limiting their use of metacognitive teaching practices.

**What Helps Teachers Use Metacognitive Teaching Practices**

The most common themes participants mentioned that may have helped them use metacognitive teaching in their classroom, ordered from highest to lowest frequency, are: (a) experiences using metacognitive practices; (b) beliefs about their relationship with learning, learning science, and skills development; (c) flexibility in the curriculum; (d) practice; and (e) other reasons, such as written reflections or students’ ability.

**a. Experiences using metacognitive practices.** The most common answer was that participants had previous experience using metacognitive practices as students or while doing scientific work. Participants described different channels through which they learned to use metacognitive teaching practices, including their TEP, certain professors, undergraduate courses, new and old supervisors, experience working in science, or professional development at their schools.

The most frequent response as to what would have helped participants use metacognitive teaching practices was learning about them during their TEP. For example, Henry stated: “I know that [the professor’s name] really used the word a lot when we were going through our program and a lot of… so grad school… was when I really
became aware that it was a thing” (Henry interview, line 26). In this excerpt, Henry explains that he became aware of metacognition and metacognitive practices in his teacher education Master’s program, noting that his professor used metacognition frequently.

In the same way, Paula mentioned that in her methods courses metacognition was “heavily encouraged.” She also referenced studying it in other courses: “In that inquiry book, in those inquiry sections that we took. Inquiry one and two. But, I truthfully, I don’t really know what it [metacognition] means. But, I do remember this thing heavily encouraged during the methods courses” (Paula interview, line 137). However, in this excerpt Paula again recognized that she never fully understood what metacognition entailed.

Table 4.9

<table>
<thead>
<tr>
<th>Themes Related with Elements that Help Metacognitive Teaching</th>
<th>Participants’ ideas (frequency)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Having an experience using it before (13)</td>
<td>During TEP (13), PD, a mentor, working as a scientist, UG professor (2).</td>
</tr>
<tr>
<td>Beliefs about metacognition’s relationship with learning and skill development (8)</td>
<td>Problem solving, creativity, accountability (2), differentiated learning, independent learning (3)</td>
</tr>
<tr>
<td>It was part of the curriculum (or standards) (7).</td>
<td>Using it because it is part of the curriculum, having seen it in the standards (5) or common assessments</td>
</tr>
<tr>
<td>Had flexibility to include it (5)</td>
<td>Control over decisions (4), non-traditional classroom settings, support from administrators (2)</td>
</tr>
<tr>
<td>Practice (4)</td>
<td>“Practice, practice, practice.” “‘force’ them to care”</td>
</tr>
<tr>
<td>Written reflections (4)</td>
<td>Write down what students think. Writing prompts at the beginning of the year and using them frequently (2), having concrete criteria for what they need to do, giving students questions</td>
</tr>
<tr>
<td>It is easy for some students (2)</td>
<td>Some students are good at it, easy for students with supportive parents</td>
</tr>
</tbody>
</table>
Like Paula, other participants also mentioned studying metacognition during their TEP and in other courses. For example, Jean explained she had learned about it as part of her coursework for a psychology minor. Steve noted that he had heard of related terms previously before starting grad school: “Well, I mean I knew them before. I’m... but, definitely metacognition was something that I’ve learned more about I think... here, doing the [MAT] program. And, maybe nature of science as well” (Steve interview, line 119). Steve recognized that he had heard the terms before, but it was not until his TEP that he learned more about metacognition and the nature of science.

Considering the epistemic part of metacognition, some teachers also learned about the nature of science during their TEPs. For example, David, who graduated from his program five years earlier, was still passionate when he described the ideas he studied during his TEP about the nature and epistemology of science. He explained it this way:

I just thought it [the nature of science] was fascinating, that I get, you got to do research without ever thinking about this science is, is as a discipline and as a human endeavor. And, we talked about it deeply. And then [it] is like... faulty and, and messy, and, and, it's just human and we try to make think that science is like a touchable, idealistic thing, and it's just, just the best we have but it's still human. And, I... to me was that class was probably the best class for all... (David interview, line 153)

Later in the interview, David related the nature of science with the term epistemology, a connection I have not found often in common discourse. I was impressed by David and the enthusiasm he expressed when he talked about the nature of science.
Nevertheless, when I asked him if he intentionally promoted these ideas in his classroom, he said no, a disconnect I will discuss in greater detail later.

Similarly, Matt also demonstrated a strong understanding of the nature of science. He described gaining related knowledge and practical skills in his professional work as a scientist:

*I like to think that I have an advantage there because of my experience working as a scientist and my wife is a scientist and so... you know, we’re always talking about you know... the use of data and what we can say and what we can’t say and so you know. I had a... as... when I was a professional the gal was my supervisor. She was super, super bright. She had a Ph.D. from Yale in biology and so. I knew right away when...when I broke some sort of scientific... you know... kinda rule when I would hand her a report I got it back because she was very good at telling me, you know, whether what, whether my conclusions could be supported by the data that I had or not. So, you know, and she was, she was really much smarter than me so... I didn’t question, you know, question that, so. I think, you know, my work experience in science using data and presenting that data and making recommendations based on that data, I think it has been valuable. Yeah, you are right. We never call it the nature of science but it was...* (Matt interview, line 140)

Matt described how he felt an advantage now as a science teacher because of his experience working as a scientist. He said that he learned to be critical about data and conclusions because his previous supervisor made him aware of it. He recognized that these were important skills to develop in his students, perhaps even more important than the content they studied in a regular science classroom.
Like Matt, David also had experience working in the sciences before starting his TEP. These experiences seemed to help participants develop a better understanding of the epistemology of science. Similarly, Emma, Elsa, and Betty mentioned participating in research projects during or after their undergraduate programs. These teachers understood the importance of thinking as scientists and the nature of science as part of their classroom. Similarly, Lucy described how her current supervisor helped her become more aware of how to develop a reflective classroom. She stated:

> But, I would definitely say, I’ve, I definitely say I would have a lot of influence um... from here with like, with our director of education and you know kind of um... my getting into her you know kinda taking me under her wing and really kinda helping guide me and because she is very involved with science education and best practices and I mean not to say that I’m, I know I’m not doing everything right. I know there’s things like I can improve and work on and understand better and incorporate more but... I would say that the [MAT] program and her probably were the biggest influences.” (Lucy interview, line 112)

Lucy recognized that her TEP and her supervisor were significant influences on her use of metacognitive teaching practices in her classroom.

Finally, when I asked Pam if she was familiar with metacognition, she answered:

> “Yes, I hear that word a lot (Pam laughs). For some of our training we talked [about] metacognition” (Pam interview, line 85). Pam explained that in the school where she worked, teachers were involved in a professional development from the Marzano Institute. This PD required them to implement certain goals and follow up with the principal, an experience that helped Pam develop awareness of students’ reflective
practices, formative assessment, and learning accountability. Like Pam, Henry also recognized his increased awareness of metacognition after a school PD, an experience I will describe in more detail later in this study.

In short, TEPs and professors who used metacognitive teaching knowledge and practices were influential for these participants in learning about metacognition and metacognitive practices. Moreover, their experience working with science, supervisors, undergraduate courses, and professional development also contributed to their experiences of metacognition and potentially influenced their teaching practices as a result.

b. Beliefs about metacognition’s relationship with learning and skill development. The next element that seemed to help teachers use (or want to use) metacognitive teaching practices was what I identified as their beliefs about the relationship between these practices and students’ learning. For example, Matt said: “I think done well really it can help... kids you know... move kinda, kinda move kids forward... so, I think it is valuable and I think it can help kids learn” (Matt interview, line 126). In this excerpt Matt described his beliefs about the relationship between metacognition and learning, noting that metacognition helps students moving forward.

Like Matt, some of the other participants believed that teaching metacognition supported students’ learning. When I asked Pam if she considered it important to teach metacognition, she answered: “[Metacognition] helps [students] kind of frame the amount of information that they’ve learned. But, not just that. Their understanding is deeper usually as well... only going back about things a second time” (Pam interview,
line 103). For Pam, metacognitive teaching practices could contribute to deepening students’ content understanding.

Frank mentioned metacognitive practices as effective not just for learning content, but also for developing skills. He stated:

To some extend [teaching metacognition] is definitely important [for the students], because, like I said, with the skills we force them to think about the skills they have or haven't developed. ‘Cause most up to this point they're kind of absorbed skills, naturally through what they can do in school and everything and at home they absorbed all sort of skills. So, this forces them to think about and to make it semi-tangible if you will. And so... (Frank interview, line 119)

For Frank, these practices can “force” students to think about their skill development and help them find evidence of it. He used the term “semi-tangible” as a reference to something concrete that could be followed up or measured.

Moreover, Paula mentioned that reflective practices in the science classroom could benefit both teachers and students. These practices could potentially help teachers understand what students took away after a lesson, a basic principle of formative assessment. For students, they could provide spaces to make connections and understand the purpose of what they are doing in the classroom. Paula explained it this way:

“Because it's a good way to, to see what the student actually learned and a good way for them to see ‘oh, okay this was the purpose of learning this’” (Paula interview, line 157).

Similarly, Elsa commented that metacognition was important for supporting students’ learning and contributing to positive changes. She described an episode where she asked students to reflect about their learning and class performance before parent-
teacher conferences. She pointed out how this reflection helped students when she gave them a list to assess their classroom performance:

*I think with some of [the students], when they kind of compared their grade and really sat down and saw it, and especially for the ones that maybe are struggling and when they really thought about it. Because it was like ten different things they had to rate themselves on, and I think when they really sat and thought like: “oh, I don’t know if I’m really doing a very good job with this” or “I don’t know how, like I’m doing my homework, but I’m just slapping down answers for a participation grade and then when we’re talking about things in class. I’m not paying attention and kind of checking my own work to see if it is the same or if I made a mistake somewhere.”* So, I think when they had to stop and think about those ten or so things they were rating themselves on they realized like, “oh, I’m not doing that very well.” And, for some of them, I’m not going to say for all of them, but for some of them after conferences, not just because they got in trouble or anything, but they started doing a better job with certain things and especially with the freshmen, the first quarter they’re kind of realizing how it’s different from middle school and I think some of them kind of realized like, “oh I’ve gotta change a few things.”* (Elsa interview, line 148)

Elsa described changes in her students after using this list for self-evaluation. Moreover, she noted that this instructional practice was especially effective with her freshmen. She expressed that the reflection could potentially help students in their transition from middle school to high school.
In Elsa’s example, she described how reflecting about learning could help students develop an awareness of the relationship between what they were doing in class and their results. Consequently, they could become responsible for their own learning. If teachers believe metacognitive teaching practices have a positive impact on students’ learning, they will use them. Thus, participants’ own experiences with metacognition are important in helping them use metacognitive practices inside the classroom.

c. Metacognitive teaching is part of the curriculum or standards. Some teachers explained that they had seen elements of metacognitive teaching in their curriculum or standards, especially those related with the nature of science. For example, Steve noted that reflection was part of his physical and Earth and space science standards:

*Reflection is I think something that is in the standards whereas students to maybe reflect on so [inaudible] they can, they learn it from the past, maybe something that they've already known, like the rocks or the water cycle or Newton's laws.* (Steve interview, line 115)

Steve might consider including some reflection when he taught the water cycle, for example, to build connections with students’ prior knowledge and then ask them to self-evaluate their new learning. However, Steve’s answer did not make clear how this reflection derived from the standards. Instead, he seemed to describe how reflecting on the content in the standards can help students build connections.

Clearly, some teachers recognized the presence of the nature of science as part of their standards. Kate stated it this way: “*I think it’s a... I’m sure that like scientific thinking is written in our, our Nebraska standards that we follow. It follows the, there’s like an inquiry section but it's in like the nature of science is in our standards*” (Kate
interview, line 142). Or, for example, Jean explained: “Oh, we definitely refer to them and we use them a lot of times for, for... especially looking at our common assessments and make sure that we’re relating them back to... um... to the standards whether it’s the nature of science, holistic knowledge, or just a life science standards um...” (Jean interview, line 98). Jean explained that she was incorporating questions in her tests and quizzes related to the nature of science and applications of the concepts they were studying in order to prepare her students for common assessments. In other words, because she knew these common assessments included items related to thinking as scientists and the nature of science, she was using inquiry instruction, but was also developing items to assess students’ thinking as scientists in her own quizzes. Jean is thus an example of how not only standards and curriculum but also assessment can guide instructional decisions.

It was not clear to me how the presence of terms such as “metacognition,” “reflection,” or NOS motivated teachers to use particular practices in their science instruction. However, because they recognized them as part of their standards, they felt they needed to use metacognitive strategies.

d. Flexibility. One of the most important elements participants identified as influential for using metacognitive teaching was flexibility in their instructional decisions and support from administration and leaders. For example, Lucy said: “It's easier to kinda to incorporate the reflection piece maybe because of the setting I am in. Because we have a little bit more flexibility here and in the curriculum, you know...” (Lucy interview, line 112). Lucy worked as part of an educational program in a zoo and was
teaching a zoology course. She explained that she was responsible for her curricular
decisions and instruction. If she observed students interested in certain topic or activity, it
was possible for her to provide more time to go in depth. Conversely, if she observed that
students were bored or not engaged in what they were doing, it was easy to go to the zoo
facilities to change activities. She also recognized that the environment of the zoo was
science-oriented and hands-on, which helped her encourage students’ thinking as
scientists rather than simply using the traditional pedagogy of teaching.

Moreover, Lucy realized she was responsible for what she was teaching. She was
the only middle school teacher and could come up with the topics and activities she
wanted to use, since she did not have a specific curriculum or the pressure of a
standardized test at the end of her school year. Furthermore, she did not use tests or
quizzes for her lessons. Her instruction was based on projects, so she could focus on
covering what she thought was important and develop scientific thinking skills.

Matt also said he could use metacognitive teaching because he had flexibility in
his curriculum. He commented that having specific standards for his course did not limit
him:

*I think that I have a lot of flexibility.* You know, and maybe, maybe I take more
liberties than I actually have. I don’t know. You know, we have you know state
standards but... I don’t feel like that limits me or that that’s like a... I don’t even
know how to describe it... (Matt interview, line 34)

Matt not only had flexibility, but also felt empowered to make his own decisions.
Later he explained he received strong support from the school administration: *“I have a
lot of flexibility to do the kind of things that I want to do in the classroom.* And, I don’t,
I get a lot of support you know, from my administration” (Matt interview, line 34). That flexibility and support allowed him to come up with new ideas, some related with metacognition, to implement with students.

For instance, when I visited Matt’s classroom, he asked students to write the school principal a summary letter about what they learned after their reproduction unit. He told me this was the first time he was trying that activity. He thought it was good for students to make them aware of their own learning and to develop their writing skills. Furthermore, writing to the principal gave them some motivation and responsibility to write with a purpose. It was also evident how Matt felt about approaching his administrator. I should mention that when I asked Matt about his metacognitive teaching practices, he did not mention this one. I thus realize that what teachers noted as metacognitive teaching practices was not an exhaustive list, and there could be some practices they did not mention or did not realize were metacognitive in nature.

Sometimes flexibility was not solely related to the curriculum, instructional decisions, and support of the administration, but was also related to collaboration with other teachers. For instance, Betty described how she was able to use more reflection in her Earth and space science (ESS) course because she had more control over her instructional decisions in that class than she did in her chemistry course: “Yeah, I do it [reflections about students’ learning] more in those classes [ESS] because that, that was, I’m the only teacher that teaches that class and I have more control over the things that we do in there and the chemistry class is a different level of kids, if that makes sense” (Betty interview, line 80). Betty explained she was the only teacher in her school teaching ESS, which she had taught before (although out-of-field). On the other hand, it
was her first time teaching chemistry, so she was following what the other chemistry teachers told her to do. The activities in the chemistry course were prescribed and all teachers were supposed to teach the same content, use the same quizzes, and follow the same pace. Therefore, Betty was not using reflection in that class. She also mentioned that the students were different. Students in chemistry were juniors or seniors, as opposed to the freshmen students in ESS. Chemistry students, then, had to be more focused on content and problem-solving than ESS students. In Betty’s case, she noted that the prescribed curriculum was not allowing her to incorporate practices like metacognition. On the other hand, because she was the only teacher in ESS, she could use the instructional time and activities as she saw fit in that course.

Flexibility was an important factor that allowed teachers to incorporate metacognitive practices in their regular instruction. Participants like Betty exemplify how the same teacher can employ metacognitive teaching based on different control conditions over instructional decisions. Of course, flexibility was not the only element that affected Betty’s decision to use reflective practices, a fact I will discuss in more detail when I describe factors that prevent or limit the use of metacognitive teaching. However, her examples reveal how important it was for teachers to have some control over their instructional decisions.

e. Practice. As with any other skill, teachers must provide students with opportunities to practice developing reflective or metacognitive skills. In my study, teachers using metacognitive teaching named practice as a fundamental element. As Lucy noted:
I think that, that has helped, that... I think for me what I would say it has to be a daily practice in class. It can’t be something that you just, they’re not going to get it if you only pull it out once in a blue moon because they are not used to having to think like that. (Lucy interview, line 126)

Frank, Elsa, and Mary, other participants who commonly used metacognitive teaching, also mentioned the role of practice. Elsa recognized that she asked students to reflect about their learning “probably like twice, two to three times a unit, it just kind of depends” (Elsa interview, line 126), while Mary asked students to come up with reflective questions every two weeks.

Practice was important because it supported the development of expertise. Teachers explained that students could employ deeper and more effective reflections when they knew how to focus their thinking. For instance, as Frank described:

But, for my second-year students our first project is building an animated guided vehicle, which is an extension of the robotics they've done previously. But, I now know that at the end of the year they have to build a manufactory including an animated guided vehicle and so that’s going to be a time we will not get there until ... April... but when we get there we will be like “hey, [do you] remember when you reflected on the automated guided vehicle the first time? now you have to build a new one. But, you're not going to build it from scratch. You are not going [inaudible], you are not going to do that, because you already had designed [one] that worked. Now it’s time to think about what could you do better. Hey, you already did that back in the first project. So, hope that make it a little more tangible.” (Frank interview, line 125)
Frank expected students would find better ways to improve their project because they had previous experience working on it.

On the other hand, as with any other skill, teachers recognized that some students were more skilled at metacognitive practices than others. For example, Gina explained: “some [students] like take [reflection] seriously, you know, the ones that care about their grades and they’ve got a pretty like open mindset, like a growth mindset. But, the ones with more of a fixed or closed mindset, they’re just like, ‘I don’t care anyway so I’m not gonna reflect on it because I don’t care in the first place’” (Gina interview, line 115). Betty also mentioned the same idea: “I think the kids that really care about mastering things and the kids that care about their grade are more likely to spend time doing [reflecting about their learning] than the ones that don’t care. Sometimes, I ‘force’ them to care” (Betty interview, line 178). It seems that students who cared about their grades were better in reflective practices than students who did not care about them, based on Gina’s and Betty’s opinions. There appeared to be a relationship between this comment and practice, since for students who are not willing to reflect and think about their learning, perhaps teachers could “force them to care,” as Betty said. It is possible that students who do not seem to care about their learning are those who need more opportunities to practice metacognition.

f. Written reflections. The last element teachers mentioned as helpful for metacognitive teaching was asking for written reflections and giving students writing prompts or criteria for those reflections. That is, they asked for a concrete, “tangible” (in Frank’s words) outcome.
For example, Betty described a successful episode using metacognitive teaching. She asked students to write her an email summarizing their learning about earthquakes after a lesson: “Yeah, I think that helped because they knew I was getting it, they knew they were typing it out so they were able to free flow with their thoughts better rather than writing it down and they like, I don’t know, they like using the Chrome Books. They would much rather do that than turn in a piece of paper, so” (Betty interview, line 188). Betty recognized in this episode that typing was successful because students could do it more easily than handwriting. On the other hand, she also mentioned that knowing she was going to read their writing helped students with the task.

Just as in Matt’s example of students writing about what they learned after a reproduction lesson, in some cases it is important for students to write with a purpose. This could also be related to the social aspect of metacognition. Of course, Betty also reflected on the importance of not being judgmental, so perhaps there are special conditions that should be considered within a learning community to promote metacognitive teaching practices.

Betty also told me she asked for a certain number of sentences to push students’ reflections, a technique Mary used as well. Both experienced some success after using this strategy. For instance, Lucy answered my question about what helped her use metacognitive teaching in her classroom:

*The thinking stems... all... you know call those out specifically and say “okay, in your reflection, when you’re writing your reflection, I want you to, your thinking stems from this category and this category” and I’ll say:’‘and I need you to use at least two from these categories” or sort of like that. So, sometimes I*
set certain requirements to kinda force them to practice that, um... other times I let them decide which thinking stems are they going to use but for, for me, for what I’ve seen, with the journals it seemed that that kinda helps them, giving them kinda prompts. (Lucy interview, line 130)

It was interesting that Lucy also used the phrase “force them to practice,” providing sentence-starters that could help students understand what they needed to write.

Writing prompts were mentioned in all the cases of successful metacognitive practices and experiences with students. Therefore, I considered the use of writing outcomes part of a more complex, deeper form of metacognitive teaching practices than asking the students to “sit down and think.”

**Summary.** In sum, teachers’ own metacognitive experiences helped them to use metacognition in their classrooms. Almost all participants recognized that they experienced and learned metacognition as students during their TEP. They also mentioned other actors, such as past supervisors and school leaders, who helped them develop beliefs about the importance of building a more reflective classroom. Beliefs about the importance of metacognitive practices also supported teachers’ decisions to include them in their regular instruction. Moreover, finding connections between metacognitive teaching and curriculum, standards, and assessment was also helpful, especially when it was related to the nature of science and developing thinking as scientists. Teacher empowerment, control over instructional decisions, and flexibility in curriculum also seemed important.

Experiences using metacognition additionally informed participants’ instructional practices. That is, teachers who were successfully using metacognitive teaching practices
described how, as with any other skill, developing metacognitive skills in students required practice. This could be especially important for those students who did not care about their performance in class, to “force them to care.” Another successful method of metacognitive teaching was using writing prompts or sentence starters, which created a tangible outcome that could be shared, followed up on, and analyzed.

Next, I review what teachers mentioned as elements that prevented or limited the use of metacognitive teaching.

**Factors Preventing or Limiting the Use of Metacognitive Teaching**

Almost 70% of participants recognized they were not using metacognitive teaching as part of their regular science instruction, or at least not using it often. Accordingly, participants mentioned more reasons for why they were not using metacognitive teaching practices than factors actually helping them use metacognition. The most common answers given for why participants were not using metacognitive practices or found it difficult to use them were: (a) they never heard references to metacognition after their TEP; (b) students did not like metacognitive practices; (c) teachers had misunderstandings about metacognitive practices, did not know how to use them, or needed more experience using them; and (d) there was not enough time to use these practices (Table 4.10).

**a. Never heard about metacognition after the TEP.** One of the most common factors that helped teachers gain knowledge and experience with metacognition was their TEP. However, many participants did not hear about metacognition anywhere else after finishing their program. For example, in the following excerpt, Steve explained that he never heard about metacognition at his school, although he did hear about reflection:
Ana: Do you hear those words [metacognition and reflection] in your school?

Steve: Reflection, yes. **Metacognition, not much (A: Not much). Not much... no.**

(Steve interview, lines 112-113)

Table 4.10

<table>
<thead>
<tr>
<th>Themes Related with Elements that Limit Metacognitive Teaching</th>
<th>Participants’ ideas (frequency)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Themes (frequency)</td>
<td></td>
</tr>
<tr>
<td>Never heard it after TEP (9)</td>
<td>“Education-y” and “intimidating,” not in the curriculum, never heard in school (7). Other teachers “disregard” these ideas (3)</td>
</tr>
<tr>
<td>Students did not like it; it was difficult for them (11)</td>
<td>It was hard (7), students found it “annoying,” “uncomfortable,” useless, “boring,” or “hard.” Students didn’t like it, didn’t see the point, “don’t care,” don’t want to think (3); they were not ready, not used, got tired, wanted the “right” answer, didn’t make “obvious connections” (2), had been “ultra-regulated,” “spoon-fed,” or tended to think “inside the box.”</td>
</tr>
<tr>
<td>Teachers did not know how to do it (8), considered it inadequate for students (5), or needed more teaching experience (6)</td>
<td>They could not grade it or could not see it (2), “shied away,” students could not do it, or it would come with time.</td>
</tr>
<tr>
<td>Not enough time (7) or needed to focus on content (4)</td>
<td>Not enough time (3). She must move on. No time for doing reflection in class (2). Teachers do not allow enough time for self-reflection. There is something else to do. Must do “other stuff.” Reflections take time.</td>
</tr>
</tbody>
</table>

Gina also noted that metacognition was not a term she used in her regular practice, learning about it during her TEP but then never again. However, she too encountered mentions of reflection: “**I guess we probably hear about reflection the most.**

**We, we don’t really hear about metacognition at school. I learned this in college in one of my education classes and that was pretty much the last time I’ve heard about it. I think it’s important, it’s just the last time I’ve heard about it**” (Gina interview, lines 131-133). Gina, mentioned that the last time she heard about metacognition was in her TEP. In addition, she explained that metacognition could be an intimidating term for some teachers: “**Yeah, yeah, maybe [people at the school] are just intimidated by**
For some teachers, metacognition might seem like a term without application in real schools.

Similarly, Frank, who worked in a vocational school, described metacognition as an “education-y” term, explaining: “Cause many of the [community college] faculty are experts on their field, such as welding or welding structures, or have been welding for years. They are expert welders and they great at what they do but they have not been trained in education, so... a very education-y thing such as metacognition they're probably unaware of it” (Frank interview, line 159). Frank explained that metacognition was related to his graduate program but was not used in other places. Moreover, other faculty at his school, especially those in technical areas, were not aware of it.

Furthermore, David’s perception was that some teachers at his school were not just unaware, but could also be “reticent,” “opposed to,” or “disregarded” ideas such as metacognition or metacognitive teaching practices. He stated it this way: “But, no, you do not hear about [metacognition]. And, I would say, sometimes a lot of teachers are, are even reticent or opposed to even, they just see all this like... I don't know, they disregard in a way all this, all these ideas” (David interview, line 183).

Paula had a similar perception. She explained that sometimes she did not find alignment between what she learned in her TEP and the practices she observed at her school. For example, when discussing thinking as a scientist and using inquiry-based teaching, she said:

*Now, does everyone use it? No. But, I do like through the program that we went through like the [MAT] program they really encourage us to do this like engaging them, ask them questions, allow them to think, so like I feel the way I*
teach is kind of different from some other teachers because I do a lot of these, and or like I like to do more hands-on or like more... I don't really like worksheets, I don't like worksheets. I like doing a lot of like notes and asking questions and verbal checking... allowing them to do activities and coloring and that kind of thing for them to understand. I really hate worksheets though. (Paula interview, line 126)

Paula felt that she had a different style of teaching after her TEP compared with science teachers at her school. In this excerpt, she commented on the overuse of worksheets for science instruction. It seems this may have been common practice at the school where she was teaching.

Thus, participants explained that although it was often mentioned in their TEPs, metacognition was not a common or regular term in their work. Some teachers perceived it as an education-y term, while others recognized that metacognitive teaching was not a common practice at the school where they were teaching. Others did not find interest or support for metacognitive teaching at their schools. However, this was not always the case. At least two participants (Pam and Henry) said they often heard about metacognition because of professional development at their schools. Lucy mentioned that after her TEP, she found a great promoter of these practices in her supervisor.

Because it was not a common concept at every school, participants’ main source of knowledge about metacognition was their TEPs or prior experiences. Perhaps this was a reason why there were not significant changes in their knowledge of metacognition. It seemed that after leaving their program, the majority of teachers did not hear about this concept again. TEPs should be aware of this trend and try to help teachers develop strong
beliefs about and experiences with metacognition so they can incorporate reflective practices as part of their teaching style. Otherwise, teachers will likely not have the opportunity to come into contact with this construct or increase their knowledge of it, as was the case with most study participants.

Teachers further explained that schools and other teachers were not the only actors reticent to metacognitive practices. The next common theme related to difficulties using metacognitive teaching involved students.

b. Students did not like to think about their thinking; it was difficult or new for them. According to participants, it was challenging for students to reflect about their thinking. Teachers who did not often use metacognitive practices expressed this difficulty, but so did those who used metacognition regularly. They described that students found metacognitive practices “annoying,” “uncomfortable,” “useless,” “boring,” or “hard.” Moreover, some participants noted that frequently students at the secondary school level were not ready to reflect, could not reflect, did not want to, did not know how, or were not used to reflection. Possible reasons included that students’ prior experience in school was about finding “the right answers,” or they expected teachers to “spoon-feed” them. In other words, participants recognized that metacognitive practices involved thinking in a different way that challenged students because they had been “ultra-regulated” or were used to thinking “inside the box.”

Participants teaching high school noted that when they asked students to explain the reasons behind their answers or think about their responses, students often did not want to elaborate. For example, in Jane’s words: “I ask questions and a lot of times I get a lot of ‘I don’t get it’” (Jean interview, line 34). Henry explained it this way: UAm... I
find a lot... kids don’t know... when you say: ‘why are you thinking that or where does that answer come from?’ You got a lot of ‘well I don’t know, I don’t know.’ And, they don’t want to think about why they thought that” (Henry interview, line 44).

Gina considered that metacognitive practices promoted a different way of thinking that was unfamiliar to students. She described it as follows: “I think especially at [the students'] age, the juniors, it’s kind of like, it’s kind of a weaning process for them. Like you, they’ve kind of been ultra-regulated their whole K-12 and now as they’re about to go out to college and like you kind of need to start figuring this out” (Gina interview, line 141). They thought students had not experienced enough metacognitive practices before, so they did not want to think for themselves. This was how Jean explained it:

I think there are a couple of things that go on with that. I think that a lot of them are spoon-fed for a really long time. And, they just expect that we hand it to them and nothing from themselves. And I think that um... In past courses, they haven’t necessarily had to think for themselves, or... or whatever... or it’s more fact-based and less about inquiry and so they never had to do thinking on their own, it’s just about memorizing facts and so it’s more of a... I have to change the whole system before they come to me [laughs]. (Jean interview, line 74)

Kate, a second-year teacher, expressed reservations about using metacognitive teaching practices as based more in her beliefs than in her experiences. In her words:

[The students] don't like enjoy writing conclusions. So, you know, I don't think they really enjoy reflecting on it. Like, I said, when it's a little more informal, like when you can kind of stick it in there, like “how do you think you did on this”
or you know “what do you think went right, what do you think went wrong,” it’s a little bit easier for them to reflect on that instead of having to like, “here write a conclusion, reflect on what you learned,” they’re like “oh no, I think that’s kind of difficult.” (Kate interview, line 124)

Kate explained that it was easier for students to reflect out loud on what went wrong in an experiment, based on her experience. If students did not like writing conclusions, it was unlikely they would want to reflect about them.

At the middle school level, teachers also found it difficult to make students reflect about their learning. For instance, Emma commented on the difficulties of student reflection:

*I think... probably because... of... as sixth-grade teacher, I find maybe I resort to try to maybe entertain them or make them active the whole time, ’cause I think that works better with like... first of all, keeping interest and behavior. So, I try to keep like a fun science class. We do labs, we do activities, we learn using fun things and I think that is probably why I've shied away from quiet, reflective, like analyze, reflect kind of things.* (Emma interview, line 103)

Emma worked with sixth-graders and knew students at that age are active and sometimes restless. She found it difficult to make them sit quietly, reflect, and analyze their learning.

Mary and Lucy, both middle school teachers who used metacognitive teaching as a regular practice in their science instruction, also described metacognition as difficult for students. Lucy noted that students did not have positive attitudes toward reflective practices because they did not find them easy; metacognitive practices pushed them to get
out of their “comfort zone.” These comments indicated that reflection was challenging for students, although such challenges are not necessarily negative. Mary explained:

“[The students] kind of disdain it and they don’t like it for a while because it’s hard. It’s not easy and it’s pushing them outside of their comfort zone in ways” (Mary interview, line 188). Lucy also reflected on how students wanted to find the “right answer” instead of focusing on the inquiry process and developing critical thinking skills:

I feel like my students are... it's kinda sad, but I feel like a lot were so programmed through the right answer, and they really struggle with that, you know. I am not so concerned with the right answer I am more concerned with the process. The right answers will come, the vocabulary will come... um... but I'm kinda interested in the process of learning and getting into that point. And so, I think for a lot of them they don't get that, they no, when I am trying to get them to reflect, get them to use like thinking skills, critical thinking skills, when I am trying to get them to analyze, and trying to get them to problem-solve, make observations, and make inferences, they I think some of them are just like “I have other work to do” you know. I think some of them are used to thinking inside of the box and we are asking them to think in a different way. And to be able to use creativity and... I think you know to think more freely really because you’re giving them the opportunity that maybe they haven't gotten before and... so... some of them really, really struggle. (Lucy interview, line 124)

Lucy described how students struggled to use reflection and metacognition, noting that these could be considered as different ways of thinking.
Thus, high school and middle school teachers described metacognitive practices as difficult for students. Participants also seemed to feel these practices were difficult for them personally. For example, Gina described this episode:

*With my physical science chem kids, like my SPED kids and the other kids, like I had a girl today and I think some of these kids have other things going on in their life so I think that maybe, like my one girl, she has mental health issues and she’s kind of been in and out of Brian West and she has been just kind of, she handed in a blank quiz today and you know I went over there and was like, “hey, like tell me what’s going on,” like trying to help her reflect out loud and she’s like, “I don’t care and I don’t wanna do it.” I was like, “can you let me help you? Like I’ll write it for you if you just tell me how to do it” and she was like, “nope, not gonna do it, whatever.”* So, I think it kind of depends on what they have going on outside of their school life and also just kind of attitude. (Gina interview, line 117)

Here Gina was trying to ask questions to make a student reflect on her performance after a quiz. The student answered that she was not interested and did not care about her assignment. This example illustrates how students sometimes experience situations that affect their learning and development at school, leading them to resist thinking. This strategy could be a way for the student to escape, as we sometimes resist being responsible for our actions. Reflection and metacognition could thus be related to deeper levels of reflection that are difficult to handle for some teachers.

After my conversations with participants, I concluded that incorporating reflective teaching could be a challenge for both teachers and students. For students, this
development could be difficult because of their own process of maturation. However, as Matt explained, this difficulty is not a reason not to use metacognition. Along similar lines, teachers who often implemented complex metacognitive teaching identified the importance of practice. Overall, participants recognized that teaching metacognition was a challenge for themselves as teachers as well as for their students.

Some of the difficulties teachers described are real and based on their experience using metacognitive practices. However, other difficulties could be related to misunderstanding or a lack of knowledge about how to use metacognition in the classroom, the next theme discussed in this study.

c. Teachers did not know how to use metacognitive practices, felt these practices were inadequate for their students, or needed more teaching experience.

Almost half of the study participants noted that they were not often using metacognitive practices. Some recognized that they were unsure or uncertain of how to do so. Often this was because they did not have a clear concept of what metacognitive practices looked like in a science classroom or found such practices inadequate for their students. Among new teachers, they also mentioned needing more teaching experience.

In general, teachers had an idea of metacognition and reflection as a process of internalization, something that happened inside students’ minds with no possibility to know what they were thinking. One participant mentioned the difficulties of assessing or using these reflections in the grade book, since metacognitive practices were related to students’ personal opinions.

For example, Gina and David noted that teaching metacognition was challenging because they could not control or see what students were thinking. David said he was not
sure whether he could make his students think about something specific. He explained he could set up activities or give them elements to provoke their thinking, but could not necessarily make students think in a certain way:

*I don’t know; I think that I don’t mind to make people think about their thinking, you can prove you invite them to think about their thinking, but I don’t know if you can make them.* But, you can at least say: “hey here are the elements, now what you do with that maybe you can get there,” you can assist them but you cannot make people think anything ultimately. (David interview, line 126)

In a similar way, Gina mentioned that working with thinking skills was difficult for her because she could not know what the students were thinking. As she explained:

*It’s just, I don’t know. I guess it just seems more practical when it’s like a physical skill versus a mental skill, you know. Like you do it this way because it’s easier on your shoulder so it doesn’t hurt it, whereas with chemistry it’s like, well we’re doing this so you can practice problem-solving and becoming mentally tough or something. It just seems less applicable to them I think when it’s a mental skill.* (Gina interview, line 26)

Gina compared thinking skills with physical skills and said physical skills were more practical, as she found it easier to show students how to progress and give them feedback on physical skills.

For Emma, asking students to reflect about their learning meant asking them to sit down alone and think, which was difficult for middle students. She said it was more effective to use fun activities or to try to keep them active. Emma noted that she could
include more metacognitive practices in her classroom, asking students to assess different conclusions instead of having them sit and analyze their thoughts: “I don’t think we are comfortable with being alone with our thoughts, a lot of us wanted to be distracted by things. So, that could be one reason” (Emma interview, line 138). Similar to most participants, Emma understood metacognition as a process of internalization, thinking individually about thoughts. In a sense, Emma is right, as middle school students would likely find it difficult to sit and think alone for set periods of time.

Moreover, Paula commented that it was not possible to grade metacognitive practices. When asked about assessment, she replied: “I could include it as a grade but I feel like it would be something more words on reflecting on, like ‘this is my own personal opinion, how should I have to get a grade for it?’” (Paula interview, line 155). Paula thought that it would be unfair to grade students’ opinions because she could not judge whether a particular opinion was right or wrong. However, metacognitive practices are more complex than simply stating personal opinions.

On the other hand, several participants said that they needed more teaching experience in order to use metacognitive practices. For example, Steve, a second-year teacher, stated: “I think there are better ways that I can do this, um... but in my second year of teaching I am still learning and running and running. So, it's like keep going along with better ways and ultimately on doing things” (Steve interview, line 21). Like Steve, almost all participants in their first two years of teaching said they were in this “survival” mode of focusing on other elements, such as mastering the content or classroom management. Metacognitive practices were thus not a priority for them. Kate explained: “I felt like a lot of times you are more focused on content than actual kids
because you are kind of figuring out like what’s your teaching and all that stuff” (Kate interview, line 50). Paula made similar comments: “Again, survival. I'm trying to get through. And I don't, I don't know. You know sometimes... You learned about these things and they are awesome and then it's kind of like ‘shoot’ like ‘I should've used this’ and I don't, you know” (Paula interview, line 171).

Matt also recognized that he did not used many metacognitive practices during his first years as teacher:

“I think, you know, even like my first couple years of science teaching, I did not even always share their score with the kids, you know. I just, I don’t know why, it seems pretty obvious that you would do that but you know, we take this map test and... we would look at it but not really talk about with kids about a whole lot” (Matt interview, line 74).

Matt went on to describe how he now asks students to set goals for their scores on the standardized test. He recognized he did not have reasons not to include metacognitive practices during his first years as teacher; he simply did not think about them.

In short, new teachers especially expressed that metacognitive practices were not adequate for students or felt they could not use them because they needed to focus on other aspects of teaching. I considered all of these reasons to be misconceptions because metacognition does not involve simply sitting down to think or expressing an opinion. Instead, teachers can provoke students’ thoughts and verify what are they thinking. This relates to the importance of learning outcomes and teachers’ explanations that practice and writing prompts or questions could help develop metacognition in students.
d. Teachers did not have enough time or needed to focus on content. Time always presents a significant issue in education, as teachers never feel they have enough time to accomplish all of their goals. Participants explained that they were not using metacognitive teaching practices because they required time, which was difficult when teachers found it necessary to keep going with the next topic, lesson, or activity. Some teachers also felt that if time was limited, they should use it on learning content. For example, Emma explained: “Next reason is... I don’t think we allow enough time of the day for self-reflection because we are always moving on to the next thing or keeping…” (Emma interview, line 138). For Emma, there was not enough time for self-reflection because she needed to keep moving to the next activity. Her use of the word “allow” was also interesting, as she seemed to take some of the responsibility for these decisions.

Paula, on the other hand, said she did not have any particular reasons for not using reflective practices. They simply did not come to her mind, or she was worried about not having enough time for them: “So, there isn't a really specific reason why it's just more like... it doesn't come to mind or I'm worried I don't have enough time to do it or I'm worried the students will do this or not because a lot of time they don’t want to do something that it's not graded so... you know” (Paula interview, line 153). Paula remarked that students did not want to invest time in activities that would not be graded. Later, she commented that she felt thinking skills and inquiry were important, but not as important content: “yes, you need to include inquiry but it's not as important as learning the content” (Paula interview, line 171). Again, participants seemed to understand the
role of metacognition in formative assessment, but this does not mean it could not be considered as part of the summative system.

Moreover, Kate explained that she needed to prioritize content and that including reflections in class took time:

…you know, just what time the, the amount of time you've given to get through content and then like moving on, reflection I think is something that a kid is getting there. But, like I said, they definitely need more time for, but like when your time goes like air, like “oh my! So, we've done this and we need to keep moving on to more stuff” it can kind of definitely get pushed to the side. (Kate interview, line 124)

Kate explained that it was easy to push aside metacognitive practices when she had to keep moving forward due to the amount of content she needed to cover.

Pam also explained that she needed more practice with incorporating metacognitive teaching practices into her lessons. She said that her focus had been to master the content she was teaching, but once she mastered the content, she could use other strategies:

I need more practice with how to incorporate it into my lessons, I, though, I think that's it, it's a, you know, the, I feel like the first part of any teaching is mastering the content knowledge itself and then you know, ask if you got in that I can get into the other parts, more so. So, be in depth of metacognition and all those things where we can talk about or how are you getting there and things like that. That's a little bit easier when you master the content. (Pam interview, line 93)
Gina also explained she was focusing on content and not using metacognitive practices as much as she would like: “Not as much as I would like. I, because this is my first year of teaching chemistry I think my, my big focus is just like more on content this year and then I think next year I can start adding in those pieces” (Gina interview, line 105). She explained that the bigger pieces of her pedagogy, like metacognitive teaching practices, could develop after she felt comfortable with teaching in the first place. For some participants, metacognitive practices were clearly not a priority. They were seen as something desirable but not absolutely needed for science instruction.

In addition to new teachers, teachers who were working on new subjects, even with several years of experience, explained they were not using metacognitive practices because they were preparing new content. For example, Betty, a fifth-year teacher, was teaching chemistry out-of-field for the first time. She told me she used metacognitive teaching practices in the courses she had taught before (i.e., ESS and biology), but in chemistry, it was different: “It’s like I’ve never taught a class where it’s like logic and you’re using logic and you’re just like solving problems and then you go and you, or you demo in real life what that looks like. I’ve never taught a class like that” (Betty interview, line 82). For Betty, chemistry was more based in logic and numbers, so this content was new for her. She was primarily focused on how to teach her new subject effectively.

In short, it is not surprising that teachers had trouble finding enough time to use metacognitive teaching practices. They also commented that they needed to feel comfortable with the content and teaching in general before adding other pieces.
Summary. Participants had experiences using metacognition in their TEPs, but many of them did not encounter the concept after they finished their programs. However, some did encounter references to reflection. Some participants felt that metacognitive teaching practices were difficult for students and teachers. For students, metacognition was difficult because they might find it boring, annoying, or useless. Teachers using metacognitive practices mentioned that students were not used to thinking in that way. For teachers, participants recognized that especially in their first years of teaching, they were focused on other issues, such as mastering the content. They also mentioned other reasons related to what seemed to be misunderstandings of metacognitive practices. For example, they believed it was not possible to make the students think about something, that it was difficult for students to reflect because they needed to sit down and think instead of being active, or that it was not possible to include metacognitive practices as part of the evaluation system of the course because opinions cannot be graded.

Table 4.11

<table>
<thead>
<tr>
<th>Teaching experience (years)</th>
<th>EQUIP’s levels of inquiry teaching</th>
<th>Total number of coded lessons</th>
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<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>63</td>
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<td>14</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>225</td>
<td>44</td>
</tr>
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</table>

Frequency of Metacognitive Teaching Practices

To study how often teachers used metacognitive teaching practices and patterns related to them, I revisited 287 lessons from thirty survey-takers who agreed to shared their information and were part of a larger research study about the evaluation of TEPs
(Table 4.11). These lessons included fourteen of the participants that I interviewed. I used the EQUIP’s indicator of student reflection coded by the research group.

From the sample, the research group coded 225 lessons as receiving an EQUIP level of 1 (no student reflection), 44 as 2 (reflection at a knowledge level), and 18 as 3 (reflection at an understanding level). The research group did not code any lessons with a level of 4. Because of the number of lessons, I decided to combine 2s and 3s for a category called lessons with metacognitive teaching (MG) and 1s as lessons with no metacognitive teaching (No MG) (Figure 4.11), assuming that reflective practices could be considered metacognitive teaching. Based on these metrics, 22% of the 287 lessons coded from August 2015 to May 2017 used student reflection (i.e., the research group coded them as 2s or 3s).

Figure 4.6 Percentage of lessons using metacognitive teaching and teaching experience from August 2015-May 2017. The percentage of lessons coded with 2 or 3 increased, especially from year 4 to year 5.
I found that the proportion of lessons with reflective practices remained steady or increased slightly as years of teaching experience increased from one year to four (16%, 21%, 20%, and 23% respectively). At five years of experience, the amount of lessons rated as 2 or 3 increased almost doubled. That is, 23% of fourth-year teachers’ lessons included reflection as part of their instruction, versus 42% of the lessons of fifth-year teachers (Figure 4.6). I concede that the number of lessons from fifth-year teachers was smaller compared with lessons from teachers with fewer years of experience. For example, we received 24 lessons from fifth-year teachers and 75 lessons from first-year teachers (Table 4.11). Nevertheless, in proportion, there were more lessons using reflective practices in the fifth year of experience. For this sample, teaching experience (measured in years) seemed to be an element that affected the use of metacognitive teaching.

I also considered other factors that could have affected the proportion of reflective practices used in lessons, such as course content. I observed that in traditional high school courses (i.e., biology, chemistry, physics or physical science, and ESS), the percentage of lessons with reflective practices did not vary significantly. I found examples of reflective practices in 16% of biology lessons, 16% of chemistry lessons, 23% of physics and physical science lessons, 14% of ESS lessons, and 24% of middle school science lessons. The percentage increased to 44% for lessons in other courses (e.g., zoology, principles of engineering, environmental science, forensic science, computer manufacturing, anatomy and physiology) (Figure 4.7).
It was interesting to observe that traditional high school courses had a lower percentage of lessons with reflective practices than other courses I deemed non-traditional. These non-traditional courses are in many cases electives (e.g., zoology, environmental science, forensic science, anatomy and physiology) or come from elective programs (e.g., principles of engineering, computer manufacturing). It seems that some non-traditional courses allow teachers to implement more reflective practices than traditional ones. Furthermore, several of the elective courses came from innovative programs that offered inquiry-based learning or allowed teachers to have more flexibility.

Consider, for example, the case of the zoology and principles of engineering courses. Lucy, who taught middle school zoology as an elective course for a program between a magnet school and the zoo, told me she came up with her own curriculum, instructional decisions, and assessment practices. She commented that she did not have specific standardized tests or common assessments as requirements. Moreover, the
students were there because they chose to take her course. On the other hand, Frank, who was teaching principles of engineering, told me that the reflective practices he was using were part of the subject curriculum. This curriculum was developed by a non-profit organization that promotes science engineering practices in K-12 education. It seems that these non-traditional courses might have more opportunities or flexibility to incorporate innovative teaching practices than the traditional high school courses.

Table 4.12

**Percentages of Lessons with and without Metacognitive Teaching Practices**

<table>
<thead>
<tr>
<th></th>
<th>Interviewed Not MT</th>
<th>Interviewed MT</th>
<th>Male</th>
<th>Female</th>
<th>UG</th>
<th>MAT Out-of-field</th>
<th>In-field</th>
<th>MS</th>
<th>HS</th>
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<td>77%</td>
<td>23%</td>
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</tr>
<tr>
<td></td>
<td>83%</td>
<td>23%</td>
<td>77%</td>
<td>23%</td>
<td>75%</td>
<td>80%</td>
<td>80%</td>
<td>80%</td>
<td>75%</td>
</tr>
</tbody>
</table>

I also analyzed other variables that could be affecting the percentage of lessons containing reflective practices (Table 4.12). For example, I checked for a difference between the participants I interviewed for this study and the rest of the teachers from the wider study. I did not find a significant difference in the percentage of lessons with metacognitive teaching practices (23% the teachers I interviewed versus 20% of the participants I did not interview). Other variables I analyzed included gender, type of TEP, whether teachers were in-field or out-of-field, and school level. I found that female teachers had a larger proportion of lessons using reflective practices than male teachers (26% vs 16% respectively), while alumni from the Master’s program (MAT) also had a slightly larger proportion of lessons using reflective teaching practices than alumni from the undergraduate program (UG) (23% vs 17%). Furthermore, a higher number of lessons with reflective practices was found in middle school teachers (MS) than teachers in high school (25% versus 20%).
Summary of Findings Related to Research Question #2

In sum, participants described a wide range of reflective practices. Responses varied in terms of purpose of the reflection (i.e., classroom management, accountability for learning, or thinking as scientists); the outcome or product (i.e., formal or informal); and the mode (i.e., direct instruction, questioning, or facilitating students’ questions). Reflections also varied based on individual or in-group participation. More complex and sophisticated metacognitive practices were oriented toward developing independent learners.

The most common metacognitive teaching practices among participants were those related with formative assessment, learning summaries, and students’ self-assessment before or after a test. Almost all teachers mentioned these and recognized the connection between metacognition with thinking as scientist. However, they could not describe metacognitive practices related to developing scientific thinking.

Certain elements helped participants use metacognition in their classrooms, such as experiences with metacognitive teaching practices during their TEPs. Other elements they recognized as helpful included their beliefs about the relationship between metacognition and learning, curricula and standards that included them, flexibility and control of their instructional decisions, frequent practice, and using sentence starters or writing prompts to help students develop the skill.

On the other hand, limitations on using metacognition included the fact that most participants did not use or hear reference to metacognition outside their education program, and they considered metacognitive teaching practices difficult for students and teachers. Participants explained that students seemed to view metacognition as boring,
annoying, useless, or difficult. Beside students’ negative attitudes toward metacognition, participants considered it challenging to include metacognitive practices as part of their lessons, because they did not know how to do so, they possessed certain misunderstandings, they did not have enough time because they were focused on the subject content, or they needed more teaching experience in order to use them.

After analyzing 287 science lessons, I observed that 22% of the lessons coded used reflection. Fifth-year teachers’ lessons had a higher percentage of reflective practices than teachers in earlier years, which remained steady. However, the number of lessons of fifth-year teachers was smaller than the number of lessons in prior years. Additionally, traditional high school courses had a smaller percentage of lessons using metacognitive practices than non-traditional courses, and middle school lessons used more reflection than high school lessons. This finding could be related to a more prescribed curriculum or content-focused expectations for traditional high school courses. During interviews, participants mentioned that they did not use metacognitive teaching practices because they needed to focus on the content. On the other hand, the flexibility and opportunity for innovation in non-traditional or optative courses could be a reason why teachers might use more metacognitive practices.

**Research Question #3:**

*What are Beginning Science Teachers’ Reflective Practices as Experiences of Metacognition?*

Teachers’ reflective practices can be considered part of the experiences of metacognition they require for understanding and improving their teaching practice, as classroom experiences can be an effective source of learning. Analyzing and reflecting
about teaching practices may also support teachers’ development. Therefore, thinking about teaching and the classroom can serve as an experience of metacognition to develop metacognitive knowledge.

Accordingly, I was interested in understanding how participants thought about their teaching practice. When I asked teachers whether they considered themselves reflective practitioners, fourteen out of fifteen said yes. Only Pam recognized that she was too busy preparing several new courses and could do a better job reflecting about her lessons. Accordingly, since almost all participants considered themselves reflective practitioners, I wanted to find a way to analyze how they were incorporating these reflections and whether the reflections might relate to their teaching practices and knowledge of metacognition.

To analyze reflective practices as part of participants’ experiences of metacognition, I used the levels of reflection described in McGregor and Cartwright (2011). I was interested in identifying how deeply participants reflected, and these authors supported the idea that a more in-depth reflection could be beneficial for improving teaching practice (McGregor & Cartwright, 2011). I used participants’ interviews and reflections during our conversation to identify the elements McGregor and Cartwright (2011) described, distinguishing between three levels of reflection: unconscious reflection (UR), conscious informed reflection (CIR), and conscious critical reflection (CCR).

I analyzed and coded participants’ interviews using the levels of reflection descriptors listed in Chapters 3 and 4. I identified ideas from the interview transcriptions that corresponded to those descriptors to code them, then classified the teachers’ type of
reflection based on the highest number of descriptors related with a level of reflection (Table 4.13). I realized that the level of reflection I found after this tally did not necessarily represent how the teacher reflected on a regular basis or all the time. In fact, I could find descriptors of the three levels in almost all participants. However, the tally was useful to find a tendency or pattern in a conversation. Understanding these patterns among levels of reflection could provide clues about participants’ practices of metacognition and their relationship with their metacognitive teaching.

**Table 4.13**

*Coded Segments in Participants’ Interviews*

<table>
<thead>
<tr>
<th>Participant</th>
<th>Teaching experience</th>
<th>Unconscious reflection (UR)</th>
<th>Conscious informed reflection (CIR)</th>
<th>Conscious critical reflection (CCR)</th>
<th>SUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paula</td>
<td>0</td>
<td><strong>20</strong></td>
<td>13</td>
<td>11</td>
<td><strong>44</strong></td>
</tr>
<tr>
<td>Elsa</td>
<td>1</td>
<td>0</td>
<td>6</td>
<td><strong>22</strong></td>
<td>28</td>
</tr>
<tr>
<td>Frank</td>
<td>1</td>
<td>4</td>
<td><strong>34</strong></td>
<td>6</td>
<td><strong>44</strong></td>
</tr>
<tr>
<td>Gina</td>
<td>1</td>
<td>9</td>
<td><strong>11</strong></td>
<td>3</td>
<td>23</td>
</tr>
<tr>
<td>Kate</td>
<td>1</td>
<td>3</td>
<td><strong>13</strong></td>
<td>7</td>
<td>23</td>
</tr>
<tr>
<td>Lucy</td>
<td>1</td>
<td>2</td>
<td>7</td>
<td><strong>27</strong></td>
<td>36</td>
</tr>
<tr>
<td>Pam</td>
<td>1</td>
<td>2</td>
<td><strong>8</strong></td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>Steve</td>
<td>1</td>
<td>5</td>
<td><strong>13</strong></td>
<td>6</td>
<td>24</td>
</tr>
<tr>
<td>Henry</td>
<td>2</td>
<td><strong>22</strong></td>
<td>15</td>
<td>5</td>
<td>42</td>
</tr>
<tr>
<td>David</td>
<td>3</td>
<td><strong>66</strong></td>
<td>9</td>
<td>7</td>
<td>82</td>
</tr>
<tr>
<td>Emma</td>
<td>3</td>
<td>3</td>
<td>14</td>
<td><strong>34</strong></td>
<td>51</td>
</tr>
<tr>
<td>Betty</td>
<td>4</td>
<td>5</td>
<td>18</td>
<td><strong>22</strong></td>
<td>45</td>
</tr>
<tr>
<td>Jean</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td><strong>13</strong></td>
<td>18</td>
</tr>
<tr>
<td>Mary</td>
<td>4</td>
<td><strong>19</strong></td>
<td>11</td>
<td>3</td>
<td>33</td>
</tr>
<tr>
<td>Matt</td>
<td>4</td>
<td>2</td>
<td>8</td>
<td><strong>15</strong></td>
<td>25</td>
</tr>
<tr>
<td>SUM</td>
<td>164</td>
<td>183</td>
<td>185</td>
<td>532</td>
<td></td>
</tr>
</tbody>
</table>

*The number in bold is each participant’s highest tally of coded segments.*

After analyzing and coding each interview transcript, I had a general sense of the level of reflection of the conversation. I confirmed almost all my overall sensed conclusions after checking the code tally, but not in every case. In at least four interviews (with Pam, Henry, Mary, and Paula) I was either unsure of my overall sense or this sense
did not match with the code tally. Thus, even after analyzing, coding, and counting those codes, I was still not convinced about some teachers’ level of reflection. After thinking about it, I came up with at least three possible explanations: the first related to my methodology, the second related to the nature of thinking and learning, and the third, the context and time of the interview.

In terms of methodology, I was aware that the ideas I coded were not always the same length, which could have influenced my overall conclusion. Some teachers used more words to describe ideas than others, so I thought a tally of coded ideas would give me a better understanding of the pattern of teachers’ reflections than the extension of the ideas. However, longer ideas might have given me an overall sense of a certain level of reflection that was different from the most frequent ideas coded.

Additionally, I used the highest number of coded segments to classify teachers’ reflection levels. However, I noticed that in cases of confusion or mismatching between my perception and the tally, the difference was not significant across levels. For example, I coded 20 segments from Paula’s interview as UR, but together CCR and CIR had 23 coded segments. Therefore, the tally between UR segments and the other two levels of reflection together was similar. The cases of Henry and Pam were similar, so this methodology had its limitations.

Moreover, the mismatch could be related to the nature of the phenomena under study. Thinking, reflection, and learning are complex constructs and not static. It is thus not a simple task to classify a teacher’s thinking and put it inside a box. I considered that certain elements could affect teachers’ reflection levels and make them shift during our conversations. Similarly, participants might have experienced events that helped them
come up with ideas they had not considered before, but which were nevertheless important for them. For example, Pam and Henry were participating in a professional development program at their school. When they began referring to that experience in their interviews, their level of reflection shifted, since they used the theories they were learning in those events. As another example, Paula, who had graduated from her TEP a few months prior, began talking about what she learned from the program during her interview. However, when she started talking about certain issues related to her classroom and the students, her level of reflection also changed. She was facing the challenges of teaching for the first time in a diverse school, preparing two different courses (one out-of-field), and dealing with the “real world.” She seemed to lower her level of reflection when referring to those issues. When I noticed these shifts, I represented them with an arrow in the tables and graphs I provide (Table 4.14).

Finally, the context and timing of the interviews could also have affected participants’ levels of reflection. For example, I was aware that Mary was in a very busy part of her school year, although she generously agreed to participate in the study. She told me the only time she had for the interview was when she commuted home from school at the end of the day. For this reason, we agreed to have a phone conversation while she was driving, and I conducted the interview in two parts. For the last part of the second interview, Mary was at home and I could hear her children around her. Thus, the time and mode of the interview could have affected the reflection level of our conversation. Talking about teaching while sitting comfortably in an office is different from trying to reflect while driving home after teaching an entire day or taking care of family after work.
Therefore, participants’ level of reflection during our conversations did not represent a final level or the way they reflected all the time. Instead, my purpose was to understand some of the differences in their practices of metacognition, in this case, their reflective practices. I also wanted to test or verify the descriptors used by McGregor and Cartwright (2011). I accordingly classified the reflective practices that emerged in these conversations, rather than participants’ abilities to reflect, as I did not have enough evidence to study the latter. Thus, I present results emphasizing teachers’ ideas as they reflected during the interviews for this project.

As a result, and considering the limitations of this part of the study, I will describe the characteristics and my understanding of each level of reflection proposed by McGregor and Cartwright (2011), adapted to science education and expanded beyond a description of a classroom episode, as the authors proposed. I articulate my understanding of these three levels of reflection based on what I found during my conversations with participants. I focus on how teachers reflected on their beliefs about effective science teaching and metacognitive teaching practices in science.

**Levels of Reflection**

As previously described, I used McGregor and Cartwright’s (2011) levels of reflection to analyze teachers’ experiences of metacognition. These levels relate to how teachers use beliefs, prior experiences, common sense, theories, and data when they think about their teaching. The authors described teachers’ reflection as unconscious (UR), conscious informed (CIR) or conscious critical (CCR), suggesting that these levels help teachers learn and improve their practice. The levels also represent an increment in the complexity and awareness (i.e., consciousness) of reflection. In other words, CCR
represents a deeper and richer reflection or more effective support for teachers’ learning than UR. I will describe each level based on what I found in the participants.

Overall, McGregor and Cartwright’s (2011) levels of reflection were useful to me in acquiring a better understanding of participants’ awareness and level of reflection during our conversation. For example, I asked participants what they considered effective science teaching and how they knew it was effective. I identified three groups of answers or levels of reflection. The first group of participants described effective science teaching as having happy students working on activities. They either felt it was not possible to observe their effectiveness or based their sense of effectiveness on perceived student engagement (i.e., unconscious reflection). The second group of participants said that effective teaching was related with students’ learning. They felt they could verify their efficacy by analyzing data, such as students’ quizzes or activities (i.e., conscious informed reflection). The third group said they wanted to promote students’ thinking as scientists and felt they could verify their effectiveness using a diverse set of tools, such as science notebooks, lab reports, formative assessment, or students’ reflections (i.e., conscious critical reflection).

In this example, the level of reflection moves from observing some students, to using data and evidence from tests, to having a wide range of tools for developing thinking skills. As a clarification, none of these levels are inherently effective or ineffective, and no single level is more important than the others. All three levels of reflection were present in almost every participant’s conversation at different points, as sometimes one is more effective than another for a certain purpose. Context also affects the level of reflection. However, I agree with the authors that the levels vary in degree of
complexity, and if the purpose of teaching is to improve students’ learning, then CCR would be a more desirable outcome.

Table 4.14 classified participants’ reflection during our conversation for this study. I also ordered participants based on their years of teaching to see if I could identify patterns between reflection and elements like teaching experience. I used these levels to determine whether there is a relationship between teaching experience, knowledge of metacognition, and metacognitive teaching practices.

Table 4.14

Levels of Reflection and Teaching Experience

<table>
<thead>
<tr>
<th>Teaching experience (years)</th>
<th>Unconscious reflection</th>
<th>Conscious informed reflection</th>
<th>Conscious critical reflection</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Paula</td>
<td>Gina/Frank/Kate/Steve</td>
<td>Lucy/Elsa</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>Pam</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Henry</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>David</td>
<td></td>
<td>Emma</td>
</tr>
<tr>
<td>4</td>
<td>Mary</td>
<td>Betty/Jean/Matt</td>
<td></td>
</tr>
</tbody>
</table>

*Arrows mean a not clear classification after analyzing coded segments.

After classifying these conversations, I noticed that, in general, first-year teachers or teachers preparing a new course tended to use more unconscious reflection than teachers with experience in a specific content area. However, this was not always the case. Teachers with several years of experience or those teaching the same course several times might also use UR. This could be related to their beliefs about teaching. For example, UR involves using traditional teaching strategies, such as lectures and worksheets. Teachers who repeat the same course tend to use more ICR or CCR, as they utilize their experience and students’ evidence to inform their teaching.

Unconscious reflection. McGregor and Cartwright (2011) described unconscious reflection as the first level of a reflective teacher. LaBoskey (1993), as cited in McGregor
and Cartwright (2011), called these “common sense thinkers.” I used the eight elements described in Chapter 3 to code reflections from the interviews (Table 4.15).

In general, participants’ reflection fell under the UR level when they described teacher-centered beliefs. I considered participants’ segments describing their need to explain, lecture, or tell students about a concept or a behavior as part of UR. Consider, for example, Henry’s comment about “giving” students the scientific method or David saying he prepared lectures and explanations for his students. Both comments focused on what the teacher needed to do rather than what the students needed to think in order to learn. I considered ideas focused on the importance of learning content as part of this level of reflection.

Teachers using ideas in this level of reflection also did not consider their past experiences as informing their teaching, perhaps because they did not have any. For example, Betty, a fifth-year teacher, commented that she was trying to go “day-by-day” because this was her first time teaching a new chemistry course, which was also out of her field of expertise. Thus, teachers in their first years of teaching tended to reflect using UR, sometimes drawing on their experiences as students or using common sense expressions or generalizations to support their teaching decisions.

Although reliance on past experiences was not common in these interviews, I did identify a few examples. After all, almost all teachers have previous experiences as students. At this level, participants used past experience to understand what was happening in the classroom and make instructional decisions, but without considering other sources or other perspectives, such as their students. For example, Emma talked
### Table 4.15

**Elements and Examples of Unconscious Reflection**

<table>
<thead>
<tr>
<th>Element</th>
<th>Participant</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning as “transmitter of knowledge”</td>
<td>David</td>
<td>I like to bring something to kids that you can use as an example or applied when, in some point, you would have to lecture or explain things. You know, it's like... I like to have like a concrete example to bring... (line 50)</td>
</tr>
<tr>
<td></td>
<td>Henry</td>
<td>I give them the method in six steps. I know there is obviously variations on that. (line 72)</td>
</tr>
<tr>
<td>Common sense, trial and error</td>
<td>Paula</td>
<td>So, that’s what I kinda try to do and a lot of times they don't want your help, they just don’t really care but... you could only try. You can lead the horse to water but you can't force it to drink. (line 19)</td>
</tr>
<tr>
<td>Getting things done for now</td>
<td>Paula</td>
<td>Last semester was a blur. Like I have been, honestly... what did I even do last semester because it's so all over the place, but yeah... it's just trying to get through. (line 107)</td>
</tr>
<tr>
<td></td>
<td>Betty</td>
<td>I mean, I really, for chemistry, I’m just taking it day-by-day because I have no idea what I’m doing and I’m just going. (line 128)</td>
</tr>
<tr>
<td>Little evidence, but the lesson appeared to run “smoothly”</td>
<td>David</td>
<td>Sometimes they are, I don’t know if you can measure, there is... there is a kid feeling comfortable in class, feeling that they can learn, they can pass it, they can do it. I mean. (line 33).</td>
</tr>
<tr>
<td>Uses his/her experience as student</td>
<td>Emma</td>
<td>That’s hard. How do you track a goal? I remember doing it in my own elementary school when we just write a goal like at the beginning of the year and at the end year look at the goals. So, I do not think I got much out of it. I don’t know. (line 122).</td>
</tr>
<tr>
<td></td>
<td>David</td>
<td>[The professor] like, like he was pointing in that direction the whole time and it took me, and I think some people in my class never got it, they just went through the hoops but they never really got it because they weren’t as accountable as I was (line 153)</td>
</tr>
<tr>
<td>Accepts his/her intuition to assess effectiveness with little or no self-doubt</td>
<td>Mary</td>
<td>A lot of it you can tell with the students, whether they’re giving you the blank stares or eye rolls or stuff like whether they, like have checked out already, how excitable they are about something. if they’re just dry and not really... I don’t know. The main measurement in that way is the engagement level. (line 63)</td>
</tr>
<tr>
<td>Considering only his/her feelings</td>
<td>Gina</td>
<td>I think they really needed that to break up all the heavy material and it was, you know we still talked about it and they still learned something from it even though it wasn’t what I intended for them to learn in that section, it’s still related to science in general and that’s okay. (line 44)</td>
</tr>
<tr>
<td>Using generalizations or unsubstantiated statements</td>
<td>Paula</td>
<td>...like I feel bad and kinda like embarrassed to say: “You know, I really don’t know the answer to this.” But, there's been a lot of times when I had to say: “I don’t know” and I just kinda feel like I don't know if they think I'm stupid but... I am not an expert and I tell them I am not an expert. (line 37)</td>
</tr>
<tr>
<td></td>
<td>Henry</td>
<td>And, to take them to reflect that before they kind of turn you off as in I just thought it and that’s all it is, they don’t want to think any more because their brain just hurts. (line 44)</td>
</tr>
<tr>
<td></td>
<td>Mary</td>
<td>I mean the students themselves inside of Catholic schools are sometimes a little bit more different than a public school, necessarily. There’s, there’s a lot of parent involvement in that regard so it’s easier to get your students to kind of do what you need to do. (line 246)</td>
</tr>
</tbody>
</table>
about setting goals as an elementary student and how she did not think this was a useful practice since she never returned to them later.

Thus, teachers using UR considered their own feelings and opinions without questioning how students or other actors might be feeling. For instance, Paula mentioned that she often used questions to make students think, but sometimes students did not want to answer them. Paula described how uncomfortable she felt waiting for answers without any reference for what students should be feeling, such as whether her questions were adequate, the timing of the questions, or why students were not reacting positively to them.

As in Paula’s case, UR did not involve questioning actions or beliefs. Instead, ideas were oriented toward trusting what teachers knew, believed, or observed, as well as incorporating generalizations. UR also included not being open to criticism or to others’ ideas. For example, Gina explained an activity using chemistry demonstrations that she deemed effective. She decided to use the exercise because she thought students were bored after working for several days on problem-solving. This may have been the case, as teachers often have a real sense of what it is going on inside the classroom. However, using more specific evidence of student feedback might allow teachers to make decisions with greater intentionality toward learning objectives.

In terms of common sense, for example, Paula and David used the saying “you can take the horse to the water but you cannot make it drink” to explain that they could not force students to learn, work on activities, or care about their development. David also used the expression to describe how he could not make students think about something specific. There was a certain degree of reasoning in these statements, but
teachers’ reflections could be further developed. For Paula, a first-year teacher immersed in a process of learning about her students’ reactions and behaviors while trying diligently to improve, that expression might have provided some comfort. Overall, common-sense expressions used in reference to situations in the classroom, as well as with students, other teachers, or administrators, were indicators of UR.

The idea of student engagement as a measure of teaching efficacy was also thought-provoking, as several teachers used this criterion to describe how they knew they were being effective. For example, Mary commented: “*A lot of it you can tell with the students, whether they’re giving you the blank stares or eye rolls or stuff like whether they, like have checked out already, how excitable they are about something, if they’re just dry and not really… I don’t know. The main measurement in that way is the engagement level*” (line 63). As in Mary’s excerpt, some teachers described effective teaching as seeing their students engaged, working, or having fun during an activity. Accordingly, these teachers could not find a concrete way to describe how to assess their effectiveness as teachers. In Mary’s case, she mentioned that she was not sure how to measure students’ engagement level. Usually her sense was based on a few comments or observations from students, such as her description of them as annoyed, rolling their eyes, or excited. I generally coded those segments as “accepts her/his intuition to assess effectiveness” or “using generalizations” because listening to or observing a few students’ attitudes toward the lesson could provide some clues, but might not necessarily be true for all students.

Thus, when participants referenced a few students answering their questions or making comments about having fun in the school’s pond during data collection (such as
in David’s case), I considered those comments as generalizations or using intuition. I decided to classify them as a lower level of reflection because teachers could use other tools to consider the diversity of experiences in the classroom.

In addition, some of the teachers who said they were concerned with student engagement during their lessons were also preoccupied with building good relationships with students. This could be understandable for first-year teachers, but Mary and David, with three and four years of respective experience, were also in this category. The relationship between teachers and students is certainly fundamental for learning, and ideally all teachers would be concerned with helping students become happy people who enjoyed their time in school. However, school is also about learning, which involves enjoyment but also challenges and effort. Learning should include tasks that can give students a sense of self-efficacy, pride, and empowerment to continue. Bearing this in mind, I conclude that perhaps a new category in these levels of reflection could ascribe more importance to building relationships, feelings, and interactions in the classroom. Accordingly, any comments related to engagement with no evidence of hands-on and minds-on examples, or evidence of learning for all students, I considered as generalizations, intuition, or unsubstantiated claims.

Teachers using this level of reflection (UR) did not question themselves or their perceptions. They trusted in their intuition or in what they observed. Reflections about surviving for now without much additional thinking were also associated with this level of reflection. Study findings revealed that participants who were oriented toward building relationships with students without concrete ways of assessing teaching effectiveness
often used this level of reflection. Teachers preparing new courses or science teachers in their first years of teaching tended to use more unconscious reflection, as well.

**Informed critical reflection.** McGregor and Cartwright (2011) identified this level of reflection with accountability for learning. This level involved the use of evidence, experience, and data to inform teaching (Table 4.16). Teachers thinking at this level questioned their teaching in relationship with learning outcomes. In other words, they reflected about what happened in the classroom to learn and improve their practice, based on their experience and evidence of students’ learning. At this level, reflections about evidence of students’ learning, whether formal (e.g., quizzes, tests, worksheets) or informal (e.g., formative assessment, thumbs-up/down), were a fundamental consideration in assessing teaching effectivity. For example, Pam described how she used formative assessment, asking students to raise their hands to show their level of understanding in order to discern whether her instruction had been effective. Similarly, Kate described how she revised her lessons as a first-year teacher and how the experience helped her decide which strategies she could repeat next year and which were not effective.

Besides evidence and experience, this level of reflection also included making connections with others’ feelings or ideas. Teachers at this level sought support from different sources, recognizing but also considering others’ feelings. They used their experiences as students, but from a teacher’s point of view, taking into account their actual context and students’ conditions. CIC also included a predisposition to evaluate performance for improvement using students’ achievement. The main difference between this level and UR, based on my findings, was that UR was centered on the teachers’ own
ideas, beliefs, and knowledge. CIR, on the other hand, revolved around reflections about what happened in a concrete situation, as well as what others might do or feel in similar conditions, and learning based on data, experience, or evidence.

Participants’ comments related to seeking information and activities in different sources were an indicator of this level of reflection. For example, Emma commented that besides Google, she was always looking for new ideas, asking other teachers for help, and checking her textbooks. Likewise, Mary listened to podcasts and searched for new ways to teach.

Table 4.16

<table>
<thead>
<tr>
<th>Element</th>
<th>Participant</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seeks support from different sources (e.g., readings, colleagues, observations)</td>
<td>Emma</td>
<td><em>I googled a lot. I use Google and I... I guess, I've been using just like the textbook CD that they gave me. It has like enacted labs on it. I have been using that for some ideas... and... I guess I ask other teachers too.</em> (line 33)</td>
</tr>
<tr>
<td>Recognizes his/her own feelings</td>
<td>Gina</td>
<td><em>Yeah I’m just trying to walk around. And you know sometimes you hit some kids and it helps and sometimes you miss some kids and when you're reading them later you're like, “dang it.”</em> (line 180)</td>
</tr>
<tr>
<td>Evaluates own practice and modifies instruction</td>
<td>Elsa</td>
<td><em>At the end of every lesson, and many times also after tests, I’ll think about what I could do next year or next week or whatever to improve something because I’m going through everything, I’ve never taught physical science so I’m kind of going through everything for the first time so just after I kind of do something it’s like, “oh I really did not care for the way that went so I need to do this next time.”</em> (line 164)</td>
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<tr>
<td></td>
<td>Paula</td>
<td><em>Or, if [the students] are sleeping when I'm trying to teach a lesson... and they just get it, like they just get it and they're really bored and falling</em></td>
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asleep, then I am like, maybe I need to do something a little bit more challenging the next time. (line 40)

| Experience informs teaching | Kate | There’s a lot of like revisions, like, now I don’t think this will work and as a first-year teacher I guess you just kind of try something thinking that it’ll work and my guess, some of them are being good but other ones are like “oh no, I won’t do that again.” (line 28) |
| Gina | I mean I’ve been thinking about [goals] often just because, one of them I have been following really well and it’s a new like pass system because I have students who like leave the classroom all the time so each student has their own individual pass and I keep them in a cup at the front of the classroom and they get four passes per quarter and so if there’s, normally if there’s like five minutes they’ll be like “oh, can I just leave and go to the bathroom?” But now, since I have the four passes per quarter they’re like “hey, can I go to the bathroom?” and I’m like “well you need to sign out your pass” and they’re like “well I don’t want to use one of my four so I’ll just wait” and I’m like, “okay, so it wasn’t urgent.” (line 88) |

| Using data to support teaching | Frank | I’ll look at the grades and that indicates to me either those skills are or aren’t being met... (line 27) |
| Pam | I kind of use it for me as a way to judge if I need to re-attack that concept or if I can move on to another concept so if I got mostly 3s or 4s I know we’re exactly where I want them to be and we keep going. If we got 2s, and 1s most of them we definitely need to do quite a bit of review and if we’ve got 2s and 3s just a little bit of review but they’ve [inaudible] for the most part gotten it. (line 53) |

| Using experience as student with meaning as a teacher | Frank | And it is for me to, first analyze that... which is a metacognition part: “How did I learn robotics?” And then I have to transition to: “okay, how can my students learn robotics?” Because, we’re coming from two different backgrounds. So, when I was, when I start doing robotics, I already had a bunch of programming experience up to that point. So, it was relatively easy to me to do so. Not so for most of my kids. So, that’s a... something that I’ve reflected on, how do I learn it and know I have to... how can I best translate that into help students’ learning. (line 115) |

Considering feelings as a part of reflection was also important. This level of reflection included recognizing these feelings but also considering others’ feelings. It also involved recognizing teaching as connected to learning, with teachers evaluating their performance and actions in relationship to students’ feelings, achievement, and goals. For instance, Gina and Steve mentioned feeling either satisfied or worried about their performance in the classroom based on students’ reactions to their teaching strategies.

Openness to improvement was another important indicator of this level of reflection. In this category, teachers considered how to improve their teaching and instructional activities based on students’ reactions, achievements, or grades after a quiz.
or test. These were all indicators of an informed conscious reflection, such as Elsa’s and Paula’s comments about assessing their performance to modify their instruction the following year.

Furthermore, teachers in this level of reflection valued learning outcomes as evidence to support their teaching efficacy and improvement. They often felt that the success of their students was their own success, using formative and summative assessment and experiences inside the classroom. Participants such as Pam, Steve, and Frank worked at schools that employed a process of teacher evaluation and goals based on students’ evidence. This might also have impacted how those participants reflected in their interviews and promoted their use of ICR. Additionally, the focus on student evidence could be related to participating teachers’ content areas, since science revolves around data and evidence. For example, Frank, in his principles of engineering class, seemed to embrace this calling for data and improvement.

**Critical conscious reflection.** In McGregor and Cartwright’s (2011) framework, this was the third and last level of reflection. For my study, the main indicator of this level was not just teachers being open to other ideas and experiences, but also using these ideas and experiences to inform their instructional decisions and compare their teaching practices to existing theories, knowledge, or criticism. Because this level of reflection included the use of teaching and learning theories and knowledge, I decided to include those reflections related to promoting students’ thinking as scientists, the nature of science, and the development of science and engineering practices (Table 4.17).

“Critical” in this level of reflection designated evidence of teachers’ critical thinking through the use of real data and experiences, informed by teaching and learning
theories and the nature of science, to improve practice. Authors also suggested including in this level of reflection an awareness of power relations and teachers’ quest for social justice as part of teaching. Aside from perhaps one teacher in this study, participants did not include reflections about social justice in our conversations, although I also did not ask questions about it. Only Frank mentioned social justice issues briefly, explaining how students from diverse background had become successful in top universities after learning professional skills in the vocational academy where he was working.

Thus, in order to qualify as CCR, comments included not just seeking different ideas, but also demonstrating a deeper understanding of different learning styles, different students, and different strategies to accomplish a learning goal. For example, Emma commented that she started with a synthesis for one lesson, then moved into an experiment, rather than simply focusing on equation memorization as the learning goal. Similarly, Matt reflected on different ways to develop students’ thinking as scientists, such as demonstrations, making predictions, collecting data, and participating in discussions.

At this level, theories informed practitioners’ teaching. Teachers reflected on the theories they learned, including during TEPs or other PD, that were helpful in improving their teaching. For example, Pam described using Marzano theories in her science classroom, while new graduate Paula discussed using the 5E and compared it with a model of instruction the school was promoting.

Besides using theories to inform teaching, reflecting about being open to criticism and taking risks was also part of this level. Being open to criticism involved, for example, active participation in feedback sessions or participants asking other teachers to observe
their lessons. It also included teaching incorporating ideas and being aware of their position on them. For example, Jean talked about utilizing more application questions in her tests as a reaction against the movement toward memorization. Similarly, Lucy described coming up with new projects and including a creative dimension. Clearly, taking risks was important, but the most effective risks were calculated or informed risks, which included a critical evaluation and ideas for improvement.

Table 4.17

<table>
<thead>
<tr>
<th>Element</th>
<th>Participant</th>
<th>Example</th>
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<tbody>
<tr>
<td>Recognizing different ways of approaching a problem</td>
<td>Elsa</td>
<td>I do try to come up with as many different ways, like visually, verbally, as many ways as I can to explain something or show something. (line 47)</td>
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<td></td>
<td>Matt</td>
<td>I think that lab activities are great where the kids are collecting data, trying to answer a question. It’s a great way to engage kids. But, I don’t think it’s the only way, you know. These kinda demonstrations where they have to kinda predict or, or… tell you know, describe what they think… (line 32)</td>
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<tr>
<td>Using different learning strategies</td>
<td>Emma</td>
<td>We checked for scorpions every day. So, that is just an example. I guess my… after that we put a synthesis and um… we… instead of just memorizing like the equation, we did an experiment where they got to look at chloroplasts in the microscopes. We captured oxygen bubbles with lettuce leaves. (line 43)</td>
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<tr>
<td></td>
<td>Betty</td>
<td>I think it should be engaging as far as the kids are asking questions and the kids are trying to gather, collect data, generate data, the kids are doing the thinking where they’re figuring out how to solve a problem but also they’re talking with each other, they’re discussing… (line 66)</td>
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<tr>
<td>Using theory to inform teaching</td>
<td>Pam</td>
<td>…professional development with Marzano, and so, we’ve been going through that stuff. And, as the school’s been talking about different things that we want to do, we’ve been setting up “okay I like to incorporate this one of the elements through talk about this design.” But, I should want to address into my classes. And so, in that way, I have been kind of setting up “okay I’d like to incorporate more of this type of thing in my classroom,” um… any one of my lessons or throughout the year, um… in that way yes, I have added certain things that I want to try to accomplish. (line 49)</td>
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<tr>
<td></td>
<td>Betty</td>
<td>Well, obviously, I want them to learn science concepts, that’s important for scientific literacy. But, I also want them to be able to like think and do critical thinking and be able to analyze things and I want them to be able to organize data and be able to come up with conclusions and arguments and back up what they’re saying with evidence. (line 72)</td>
</tr>
<tr>
<td>Using “thinking as a scientist” or scientific practices</td>
<td>Lucy</td>
<td>For instance, after you came and observed with the Monarch tagging, the next few class periods we were looking at real data on the Monarch migration over the last two decades and then we’re looking at current data too. And, I just went through their journals… last week… and looked to those I can see right away what students were understanding… the data analysis, were understanding the graphs and what they’re looking at. They were able to make inferences… (line 24)</td>
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</table>
This level of reflection was also related to teachers’ awareness of themselves, their teaching styles, and their own points of view. Above all, it required a deep commitment to assessing practice, using the best practices, and improvement. This emphasis on improvement was also guided by openness to other approaches, as well as learning goals, others’ criticism, and especially a self-awareness of beliefs, strengths, and limitations. Participants at this level were open to other ideas but could also compare themselves and identify which of those ideas worked for students’ learning or did not work for them and why.

Six teachers with a diverse range of experience levels used this level of reflection. Some of them were also participating in PD and school-wide practices, such as Lucy and...
Jean. Others, including Matt, Emma, and Elsa, had a special interest in developing scientific skills in their students. For Matt, his years of experience working as a scientist helped him develop this interest. Emma and Elsa, although they had fewer years of experience, had also worked in science research and thus had a good understanding of how to develop students’ ability to think as scientists.

**Reflective Practices and Teaching Experience**

In general, all of the participants in this study identified as reflective teachers. They described reflective practices “on the spot” (i.e., reflection on practice) and after teaching events (i.e., reflection in practice). The most common level of reflective practice was CCR with six participants, followed by CIR with five participants (Figure 4.7). The first-year teacher and teachers preparing new courses, especially those teaching out-of-field, tended to use more UR.

*Figure 4.8* Participants’ levels of reflection and teaching experience. A bigger circle represents a higher frequency of teachers in that level of reflection.
Almost all of the teachers in their second year of experience, the largest group in this study, tended to use CIR or CCR during our conversation. Teachers with more than two years of experience also demonstrated more conscious reflection. It seemed that the first year of teaching was important for them to develop awareness about improvement. Nevertheless, I found teachers with three and four years of experience using UR as well (e.g., Mary, David, and Henry). Therefore, it seemed years of teaching experience might impact how teachers improved their reflective practices. However, there are other elements that could have affected these reflections. Below I discuss some of factors teachers perceived as helping or limiting their metacognitive practices.

Table 4.18

| Factors Assisting Participants’ Reflective Practices as Experiences of Metacognition |
|---------------------------------|---------------------------------|
| Themes (frequency)              | Participants’ ideas (frequency) |
| Collaboration with a peer or group of teachers inside/outside school (11) | Collaboration with a peer (3); groups inside/outside school (e.g., PLCs [2], New Academy Teacher [7]), whole school (2), supporting new teachers (2) |
| Setting up goals and assessing them; mentoring experiences (9) | Using data and evidence to assess goals (4); having someone trusted or experienced to observe teaching and provide feedback (3) |
| Professional development at school (4) | School leadership (3) |
| Registering experiences as part of planning (4) | Teaching experience (3) |
| Being open to learning (3) | |

As part of this research question, I also wanted to know what factors could affect beginning science teachers’ reflective practices as experience of metacognition? I asked teachers how their school supported them in reflecting about their practice as part of their experiences of metacognition and what limited their reflective practices. I will describe their answers next.
What Helped Teachers’ Reflective Practices as Experiences of Metacognition

Participants mentioned the following occasions when they thought about their teaching during school: (a) Collaboration with peers inside and outside school; (b) setting up goals and assessing them with a mentor or school administrator; (c) whole-school professional development; and (d) planning and registering experiences for next year (Table 4.18). Participants in this study reflected about elements that helped them think about their teaching practice for improvement. These moments were related to the spiral of reflection mentioned in prior chapters.

a. Collaboration with peers. Collaboration with other teachers was the most common theme mentioned by participants. For example, first-year teachers found it valuable to talk with another teacher about their lessons and their adaptation process in a new school. They often connected with other new teachers looking for support. For example, Kate explained:

One of the new teachers at the school, me and her actually graduated on the same year of high school, so... We talked quite a bit about things like that. I guess that's probably more like extracurricular talk too, and [we] talk about like well this, we did this yesterday and this didn't work. Then, I'll kind of give her ideas too about like lots of like classic, like last year this is what I ran into and stuff like that so... (Kate interview, line 58)

In the excerpt Kate described how working in a more informal setting with another new teacher helped her think about her teaching, evaluate what worked and did not work, and share ideas with a peer. It seemed important to find a peer in the same circumstances to seek support from without feeling judged or uncomfortable. New
teachers deal with many challenges, so these interactions seemed to be a good channel of support.

Looking for a colleague in similar circumstances was not exclusive to new teachers. Jean, a fifth-year teacher, said she also worked together with another biology teacher at her school, which helped her think about her lessons and how to improve them: “Um… it’s one other biology teacher. I have a couple of other biology teachers that teaches and um… one of them specially, she and I like… would take time during the summer and work on things and revise things all the time and make them better” (Jean interview, line 149). Again, this was an informal collaboration, with teachers working outside of school to improve their practice.

These interactions could also sometimes be formal. Participants described how schools developed programs to help them reflect and improve their practices. Schools often had mentoring programs for new teachers, whether these were one-on-one, school-wide, or with other schools. Paula explained: “So, we do… [the school administration] encourage us to talk with our mentors. We have these like new to [name of school] meetings. So, like all the new teachers, math, science, English teachers, all of the new people they bring us into these meetings monthly and have us talk about like how are things going, what to do during an event the school has.” (Paula interview, line 65). These meetings also helped teachers acquire information about school events.

This support for new teachers sometimes extended outside of school. Kate, who worked in a small school district, described attending a “New Teacher Academy” every other month, where she learned new models of instruction that helped her improve her teaching. Kate explained that the Academy was also a form of professional development
related to instructional elements, such as Canvas course software, as well as classroom management issues:

*The New Teacher Academy is once every like two months … they do kind of like a setting up effective lessons like they have one called instead of like a 5E lesson, they called I think it’s GIMAC or something, it's just like how to set up like effective lessons so we did that last time to just kind of help with like, like new teacher specifically. But, they also do other things, like I said, like a Canvas training, or had other people go and like a critical, like a crisis management they’ll go up there and do [inaudible] things or something like that.* (Kate interview, line 68)

New teachers found it helpful to meet with colleagues, whether from their own schools or other schools, and to realize they were having some of the same struggles. Schools also apparently promoted these experiences for new teachers to provide them with support and help them during their adaptation phase, an admirable practice.

Other efforts to promote collaboration among teachers included developing learning communities. Participants mentioned they had meetings during school hours to work in small groups and think about teaching improvement, which they called professional learning communities (PLCs). Gina explained: “*Well, there’s three of us that teach chemistry and we talk a lot in PLC. We just kind of brainstorm like a week ahead like ‘hey, what can we do? How can we keep students engaged this week?’ and we look at resources on the internet by looking up labs*” (Kate interview, line 64). Similar to Gina, Betty mentioned that at her school they worked in PLCs to develop and analyze common assessments. However, teachers did not always use this PLC time for teaching
improvement. Sometimes teachers were busy with other school-related issues or were not dealing with the same problems, which made PLC time less effective than it could be.

Teachers in smaller schools also experienced learning communities, but in a different way. For example, Matt said: “Maybe it’s the advantage to a small school and kind of the set up that we have where our team meets every day and talks about... what we’re doing” (Matt interview, line 56). Matt explained he met with other middle school teachers often to talk about students, common activities, and assessment, which made it easy for him to have time to think about his teaching. Kate also said that working in a small school helped her interact with other teachers without pressure, inquire about what her colleagues were doing, and ask for help when she needed it: “I don’t feel quite as much like pressure because I know like I can like teachers would tell me what they’re doing in their classroom and it’s just a little bit more like novice, I guess it’s not quite as much pressure” (Kate interview, line 62). It seems that formal and informal learning communities provide teachers with support to think about improvement. These face-to-face interactions were important to them and were described as helpful for reflecting about their teaching.

Face-to-face interactions with peers were participants’ most frequent method of collaboration with other teachers. It seemed noteworthy that participants did not mention other methods more often, such as using technology. Teachers did describe using the internet and Google searches when they needed to improve a lesson or find new ideas to teach a topic, but these strategies were mainly for locating new materials. Matt, for example, said he followed web pages from other teachers to get new ideas. Nevertheless, he did not communicate with these teachers or post his activities or ideas for others to
use. Overall, participants used technology to search for activities more than to collaborate with other teachers.

Gina was the only teacher who mentioned a collaborative experience using technology. She recognized the importance of collaborating with other teachers in her school district, sharing documents using Google. As she explained:

_There’s like, with all the physical science chem teachers in the district we have like this Google Drive where everyone just kind of dumps lessons in the drive so you can go in there and click on like whatever unit you are and you can see lesson plans like from teachers from [name of school 1] and [name of school 2] and [name of school 3] put in and you’re like “oh, that one’s really cool, I’ll do that one today.” So, that’s really helpful._ (Kate interview, line 64)

Gina and teachers in her district used Google technology to share their lesson plans and see what other teachers were doing. Gina considered this an effective tool for improving her teaching, and using technology seemed like a helpful way for teachers to look for new classroom strategies. However, it appeared that for thinking about teaching, they appreciated face-to-face interactions.

In short, learning communities and face-to-face interactions with peers helped participants improve their teaching. In all of the interviews, participants described a collaborative, non-threatening, and nonjudgmental environment as necessary. In some cases, they found these conditions with a peer, with a group of teachers, or even in a larger community. Schools and school districts seemed aware of the importance of promoting collaboration and reflection among teachers, and these strategies could support any level of reflection. For example, during interactions teachers might use prior
experience to explain their development of new activities for students. As in Betty’s example of a PLC, collaborations could also be used to analyze common assessments and make decisions about instruction using CIC. The New Teachers Academy could also promote CCR if leaders used teaching models to help new teachers implement active learning. However, larger experiences like the New Teachers Academy could have a greater impact on developing CCR, meaning using theories to inform teaching, than other kinds of interactions. On the other hand, a teacher who feels isolated could be limited to unconscious reflection. For example, Mary, a fifth-year teacher with a reflection level of UR, recognized that she was working alone most of the time at her school.

b. Setting up goals and assessing them. Setting goals could be a useful way to think about teaching improvement. 60% of participants mentioned that they were required to set up teaching goals to improve their practice, which they often did at the beginning of the year. It was frequently a school activity and part of their teacher evaluation process. Often, an administrator followed up on these goals and asked teachers to collect evidence (e.g., student artifacts) throughout the school year to assess their progress. Some teachers considered this an effective practice for thinking about their teaching and how to improve it.

For example, Steve described goal-setting this way: “I discuss my goals with my administrator at the beginning of the year and then I collect artifacts throughout the year and then I show those artifacts to my uprising administrator in March and then we look at that together and see if I've, my goals or it's something it's [inaudible] direction didn't work out” (Steve interview, line 43). All of these efforts helped Steve think about
how he could improve as a teacher. Since the administrator asked him to collect artifacts, that is, to show evidence of his goals, this practice could also promote CIR.

Steve commented that this process of observations and feedback from administrators was helpful because it came from someone experienced that he trusted, and it was genuine. He said: “I think it's good because it's coming from someone that I trust, that I respect, from someone that I know has experience in the classroom and so I take that very seriously, their comments and concerns I know, they're... they know what they are talking about. And, they're being genuine” (Steve interview, line 49). Steve was a good example of how setting goals for teaching and receiving feedback could be an effective way to promote metacognition. Steve felt supported by his administrator and these practices were helpful for him to think about his teaching. However, these goals were not always as effective for all participants, as I will explain later.

School administrators seemed to be responsible for providing feedback and following up on teachers’ goals. Moreover, schools sometimes had mentoring programs for new teachers to help them become aware of what they wanted to focus on and improve. Kate described her mentoring experience as follows: “we did a lot of that last year with my mentor when I had in [name of the school] we did a lot more mentor-mentee like setting goals for yourself. So, I did a lot of that last year like what I wanted to get better with a quarter to quarter” (Kate interview, line 46). Kate described how she worked with her mentor during her first year as teacher. She set up goals with the mentor and had short periods of time (i.e., quarters) to work on them. She considered this process important for reflecting about her teaching. Although not all mentoring experiences were
as structured as Kate’s, almost all participants mentioned them as an opportunity for reflecting on their teaching.

Setting goals and following up on them was an important strategy to help teachers think about their teaching. Schools and mentors who asked for evidence and could potentially be supporting CIR. On the other hand, when I asked participants such as Steve or Matt whether they asked students to set up their own goals, they told me they had not done so (or at least not often). This was a common answer among participants. Therefore, experiences of metacognition could not necessarily be transformed into metacognitive teaching practices. If these experiences were not embedded in science instruction, it was difficult for participants to transfer the experience into their classroom.

c. Whole-school professional development. Participants described setting teaching goals as a common practice in their schools. Sometimes these goals and observations helped them become more reflective about their teaching practices. As mentioned previously, TEPs also helped teachers become more aware of reflective practices. Besides these experiences of metacognition, whole-school PD seemed effective for promoting practices of metacognition among teachers, especially developing CCR. However, these experiences were not common.

For example, Pam described becoming more aware of how to share learning objectives with students and using different learning strategies after Marzano PD in her school. She explained she set up goals related to this PD, which helped her think about and improve her teaching practice:

I kind of... try to make sure that for each unit I have a lesson objective and that I talk to the students about it before hand and then also work with different ways of
you know, for each of these workshops that we've done they'll attach a different 

one of the sections and we'll have to go through you know round one of our 

lesson objectives and then walk through it how we're going to use these different 
techniques to try and bring the different elements into the classroom or so. And 
so, we actually get some hands-on, here's what I'm planning, here's how I can 
add in different things to get to one of these goals. Um... and use them in my 
classroom. It's for that is really helpful. (Pam interview, line 69)

Pam described using lesson objectives after her PD and dedicating time during 
workshops to plan how to use those tools in her teaching. These were also part of the 
goals she needed to submit for her evaluation planning. In other words, her goals were 
aligned with this PD, which in turn helped Pam develop awareness in her reflective 
practices.

Henry was also participating in a whole-school professional development as part 
of the instructors’ group. He described how teachers at his school were becoming more 
reflective after these sessions:

We had staff meeting yesterday, my principal and I did a… an activity with the 
rest of the staff of... for this Danielson [model of instruction] and... he hands it 
out different scenarios and they had to identify which part of the model, the 
teaching model where they came from, and so... and what we're going to go 
forward with that is okay would this person be ranked as basic, or proficient, or 
distinguished, or unsatisfactory or how would we do it. And so, things like that, I 
think the whole school is kind of on a transition to being much more reflective 
and… in that way. (Henry interview, line 90)
Henry explained that the administrator was personally involved in this PD, and the entire school was more reflective following sessions over a new teaching model. Using a model of instruction could help teachers compare teaching practices with the model, be critical of what they were doing, and examine concrete aspects of their teaching they could modify. This was an example of how school-wide PD could promote CCR.

In short, PD, especially involving the entire school and administrators, seemed effective at promoting awareness of teachers’ reflective practices. School leadership was an important element, as teachers found reflection and improvement most effective when they felt supported by administrators and had a concrete base (e.g., ideas from a PD) to set up goals.

**d. Planning periods and registering experiences.** Teachers also found it helpful to plan and document their lessons in order to use them the next year. First-year teachers were especially aware of the importance of recording their thoughts after using an activity. As Paula noted:

> And then also like don’t, don’t slack on the planning part because I know that this is going to help me next year...So, next year is going to be easier when I am like “okay, I know what I’m doing. I taught it before and I know what I am doing. I know this worked, I know this didn't work, how can I change it.” So, it's little tweaks rather than I'm starting from scratch. (Paula interview, line 201)

Paula commented on the importance of teachers registering and filing their activities to reuse and improve them next year. Some teachers said they included short
comments about how the lessons went and how to improve them. For Paula and other teachers, keeping lessons organized was an effective strategy.

Matt, a fifth-year teacher, also said he reflected about his teaching while he planned new lessons, a process involving information from the previous year. When I asked him how he thought about improving his teaching, he responded: “I'll build a new lesson, you know. I don't just copy and paste... last year's... and so, it's got easier for sure” (Matt interview, line 42). Matt used material from past years, but not simply to “copy-and-paste.” Having the experience and the material helped make this process easier than in his first years as teacher, a practice that could help promote CIR.

Teaching experience and having lessons documented were useful strategies. For instance, Matt explained that teaching the same course for five years helped him work to improve it: “I taught photosynthesis in 7th grade for five years. This is my fifth year so you know, I like to think that every year... I get a little better on it. Some things, some years I'm probably, I probably take steps back maybe, I try something that doesn't work as good as I did before, but... yeah” (Matt interview, line 36). Teaching experience helped Matt try new strategies and better understand what worked and did not work in the classroom.

Prior experiences clearly helped teachers reflect about their teaching and develop awareness in their reflections. Participants mentioned planning periods as important moments for reflection. While some teachers worked alone during planning periods, others described how they planned and acquired ideas from collaborating with peers, such as PLC groups. Documenting and keeping lessons organized, including adding comments about what happened in the classroom and what needed to change, were good
practices for new teachers to attain CIR. Moreover, this seemed to provide evidence for how an outcome or learning product might deepen an experience of metacognition.

e. **Being open to learning.** Some participants, especially more experienced teachers, showed an attitude of openness to learning. These teachers were willing to reflect and use new strategies to improve their practice independently of school programs. For example, David mentioned that he was always looking for new ideas to use in his classroom: “I am never happy. I mean. I’m sorry, I am never happy but I know, you can always do, you can always do something better and...” (David interview, line 171). David described himself as “never happy,” demonstrating an awareness of his need to try new techniques and improve his lessons. Matt also mentioned that he used the summer to improve his teaching:

*I guess I always try to focus on something over the summer to improve upon.*

*So, in that way maybe that’s a goal, but I guess I don’t ever think that that’s a goal other than "hey, this is what I’m going to focus on," something every summer to try to get better at whether it’s learning, some new content or getting some new materials ready to go for the next year or something like that, so...* (Matt interview, line 36).

Matt described the summer as his time to focus on improvement. He also mentioned that he did this because he wanted to, not because it was something the school asked him to do. According to Lucy, however, “You just find time. You just make time” (Lucy interview, line 69). Participants seemed to value learning and agreed to invest even their free time to improve their teaching. These teachers appeared open to learning, an important attitude related with reflective practices. Moreover, I noticed participants who
commented about finding their own time were fourth- and fifth-year teachers (e.g., Jean, Matt, Marry), so when teachers are committed to improvement, they will find opportunities to reflect.

Being open to learning could also contribute to CIR and CCR. Teachers should feel the need to improve and change in order to develop reflective awareness. As in every model of change, this felt need is an important step.

In sum, collaboration among teachers was an important practice for helping them reflect about their teaching and deepen their reflective awareness. This collaboration could be informal, with a peer, or part of a school program, such as a mentoring experience or PLC. Goals were also a common practice teachers considered helpful for promoting metacognitive experiences. Goals and follow-up meetings could be an effective strategy to deepen reflection into CIR. However, a negative goal process could lead to useless or busy work.

Moreover, professional development, administrator involvement, and goals seemed useful in helping teachers achieve CCR. However, teachers also need to have an open attitude toward change and improvement in order to use these opportunities to think about their teaching. Finally, CIR can be promoted when teachers document their lessons and use that information when they plan new lessons.

Factors Limiting Experiences of Metacognition

Some of the limitations or elements that did not allow participants to reflect on their teaching were: (a) not having enough time during school; (b) situations in which setting up goals felt like busy work, since no one followed up on them; and (c) lack of teaching experience (Table 4.19). Some of the themes teachers described during
interviews did not support reflective practices. Here I explain the most common of those themes.

Table 4.19

<table>
<thead>
<tr>
<th>Factors Limiting Participants’ Reflective Practices as Experiences of Metacognition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Themes (frequency)</strong></td>
</tr>
<tr>
<td>No time for thinking about teaching during school (7)</td>
</tr>
<tr>
<td>Setting up goals was busy work; no one followed up (5)</td>
</tr>
<tr>
<td>Teaching experience affected thinking about teaching (4)</td>
</tr>
</tbody>
</table>

**a. No time for thinking about teaching.** The main theme that arose when teachers described experiences of metacognition was that they did not have time to think about their lessons during school. Teachers, especially in their first year, described their experience as “I work myself to death” (Paula interview, line 61) or “survival mode” (Gina interview, line 88). It is not a surprise that teachers did not feel they had enough time to reflect about their teaching, as they were all significantly busy. Usually they had a large amount of work (e.g., teaching different courses, preparing activities, grading, re-testing, mentoring students) or different tasks (e.g., coaching, participating as leaders in PLCs or school PD) they had to complete during a day. This busyness could also affect their level of reflection.

As one example, Betty was teaching out-of-field ESS and chemistry while also working as a cross country and track coach:

*Yeah, well I coach in the fall, I coach cross country in the fall and I coach track in the spring so I’m pretty much coaching almost the whole year. Some of it’s good*
and some of it’s bad. **Like it doesn’t help me in the fact that I have not very much free time.** Like I don’t have enough, sometimes I don’t feel like I have enough time to be a good, the best teacher that I can be because I miss school a lot, I miss like once a week during the season and then I also don’t have as much planning time. So that doesn’t help me. (Betty interview, line 58)

Betty explained she had to miss school sometimes because of her coaching responsibilities, which took time from her planning. Having an extracurricular assignment reduced the time Betty and other participants had to plan or think about their teaching.

Other new teachers who were preparing several different courses said it was difficult to find time for their teaching. For example, Pam a second-year teacher, was preparing applied science, physical science, physics, anatomy and physiology for the first time. She explained she was concentrated on making it through the experience. When I asked whether she was a reflective teacher, she answered:

*Not as much as I should be. I would say, because I feel like I don't have enough time to sit back after class and say “okay, how did that go, what things should I improve upon and what things should I change.” I find that this year’s volume of classes that I have that I'm more or less going ‘okay, I'm done with that one, let's go to the next one.’* (Pam interview, line 133)

Pam explained that she did not have enough time to think about her lessons because of the volume of classes she was teaching. Even though she was participating and actively implementing ideas from her PD, her level of reflection was not CCR.
Sometimes teachers had time scheduled for collaboration and reflection, but these times were not used as intended. For instance, Betty commented during her interview that even though she had a time set in her schedule for PLCs, teachers were not using that time to collaborate and think about their teaching. Instead, they were using it to complete administrative tasks:

*Lately, we haven’t had any time for collaboration because we’ve been trying to deal with course schedules and things like that and so we haven’t had actual time to collaborate and I’m a PLC co-leader so I need to make sure that that happens because I really need that time with him* (Betty interview, line 146).

**b. Setting up goals was “busy work,” since no one followed up on them.** As explained previously, several schools had programs to help teachers reflect and improve. For example, participants mentioned mentoring programs for new teachers, group meetings, administrators asking for goals and providing feedback, and PLCs. Nevertheless, these activities were not always effective.

For example, Elsa said that for her, submitting goals was not helpful for thinking about her teaching. She said she did this because the district requested it, but the timing was difficult and she submitted goals that were not meaningful to her. Moreover, she was not sure whether her administrator read her goals, and she never talked about them after submitting them: “*We had to submit goals online in this kind of system that we have for our district so I mean I don’t know if my administrator has read those at any point but I know that I had to submit them*” (Elsa interview, line 90).

Like Elsa, other participants mentioned that while they set goals for their evaluation, they also had internal goals or other goals that mattered more to them but did
not share them with administrators. She considered this goals activity “busy work” (Elsa interview, line 92) that she had to complete to meet a requirement. Other participants (e.g., Jean, David) spoke similarly about their goals.

c. Teaching experience affected thinking about teaching. Participants in this study had different situations based on their teaching experience. First- and second-year teachers had a different perception of time and teaching than fourth- and fifth-year teachers. For example, when I asked Kate, a second-year teacher, whether she was reflective in the classroom, she answered: “As far as a new teacher, I don’t... I think you have to be very reflective because you don’t know what works and you have most of the time no idea what you’re doing and you have to, you have to really think about how can you make this better for next year, what can you do differently, so I would say yes” (Kate interview, line 144). This was a typical answer among teachers in their first two years. Therefore, this could be one reason why new teachers used more UR during our conversation. Teachers during their first years felt they needed to reflect about their teaching because they believed they did not know what they were doing or what worked for students. However, they also felt busy trying to keep up with their responsibilities at school and adapting to their new position as teachers. Moreover, they sometimes did not have prior experiences to inform their reflection. For example, this was Paula’s first year of teaching, and she was also teaching outside her area of expertise. She lacked any experience save her own experiences as a high school student, so it is not surprising she was using UR to reflect about this course.
Clearly, time for reflection could be a challenge for teachers in their first years because many experiences might be new for them and they did not necessarily have any prior teaching experience to inform their reflections.

**Summary.** New teachers sometimes found it difficult to reflect on their teaching when they were busy preparing new materials or working on different activities that required their attention at the same time. Some schools had programs or activities to help participants think about their teaching, such as setting goals or collaboration meetings. Nevertheless, if teachers did not consider these practices important, if the timing was not right, if they had other things to do, or if they did not know what to set as goals, they did not use those activities effectively as reflective practices. Finally, lack of teaching experience could also prevent teachers from deepening their reflective experiences.

To verify these findings, I used the spiral of reflection to see whether there was any relationship between how teachers reflected (i.e., level of reflection) and with whom they reflected, findings I present in the next section.

**Spiral of Reflection**

Teachers described several forms of interaction that helped them reflect, such as discussion with peers or participating in professional development. Metacognition has an important social element, as described in Chapter 2. York-Bar et al. (2011) organized these interactions, describing teaching reflection like a spiral of interconnected levels. The spiral of reflection moves outward through individual reflection, reflection with a peer or a mentor, reflection with a group of teachers, and finally, reflection as whole school. Therefore, I wanted to know whether reflective practices in the outer levels of this
spiral (group and whole-group reflection) could have an influence on the reflection participants shared with me during our interview.

Based on their description of these practices, I classified participants’ reflection using the levels of York-Bar et al.’s (2011) spiral of reflection (Table 4.16). I use Henry as an example to explain these levels and how I assigned them. I describe his progression from the outer to the inner level, which in Henry’s case made more sense.

Henry explained he reflected in several ways during school. He was facilitating, together with the school principal, a workshop about a model of instruction (Danielson Framework for Teaching). They gathered the other teachers to revise the model and plan how to use it in the classroom. As Henry explained, the entire school, including the leadership (i.e., the principal) was involved in these reflections during periodical staff meetings throughout the school year. In the spiral of reflection, this is the outer level, when the whole school is involved in the reflection. I noticed the reflection also revolved around a model of instruction and was thus oriented toward a more critical conscious reflection informed by theory.

For these meetings, Henry explained, facilitators formed groups and teachers shared how they incorporated some of the framework’s elements: “Okay, so for this one it’s just they, they were at a table, we assigned groups of four of them and they were all sharing with each other what’s… what component they were going to cover, and so next time at the staff meeting they’re just going to re-share with everybody” (Henry interview, line 94). In the spiral of reflection, the group level involves reflection with a group of teachers, in which the teacher does not have control over who is in the group. Thus, the group members are not those who work together regularly, teaching the same
course for example. This might be because different experiences can enhance reflection by considering different points of view. In Henry’s example, the framework facilitators (Henry and the principal) formed groups with school staff. Within the groups, teachers shared components they wanted to use in their classrooms, then explained how their experiences went at the next meeting.

The peer or mentor level of reflection occurs when teachers share with a colleague or mentor. In the case of Henry’s school, he described how after the workshops, the school administrator came to observe a lesson: “Yep, we have meetings. And, actually, they have observations. So, we have one observation each semester and we have a meeting with feedback after that. And for those we’re supposed to have evidence, as well” (Henry interview, line 100). Henry described how teachers had a classroom observation with the principal and an interview to follow up on this process. For these feedback sessions, the teachers had to provide evidence of the work they were doing, making these sessions an opportunity for reflection. Again, the feedback session was based on the framework and evidence, promoting a more conscious informed reflection. The reflection provided one-on-one time with a mentor who helped teachers monitor, plan, or evaluate their ideas. Reflection in this level could occur with either a peer or group of peers.

Finally, the inner level represents personal reflection. As Henry explained: “For me, I guess, thinking about my thought process when I was designing a lesson. So, what is my goal. And reflecting on that” (Henry interview, line 14). In this excerpt, he described how he reflected about his lessons individually while designing them and aligning them to the purposes or goals for that lesson. It is important to notice that he was
working on a formal outcome (i.e., the lesson plan), and while did not mention it, this level of reflection could also be aligned with the framework being implemented at his school.

In fact, Henry explained that working as part of the facilitating team and using this model of instruction was helpful to develop a reflective community in the school. Moreover, he said that words like “metacognition” were now common after these workshops: “we’re transitioning to a... a teaching framework and we are using the Danielson model. The Danielson framework for teaching. And, a lot of that, so... it’s in four domains and the fourth domain is um... I have it here... is professional responsibility. But it is a about a lot of reflecting. And, you know, how could this go. So, we do, uh... I am part of the team that is training our staff. And so, when we meet, we have use the word many times, metacognition and things like that” (Henry interview, line 28). For Henry, metacognition was a common term because he was using it in school as part of this framework of instruction.

Henry’s experience exemplified how schools and PD might help teachers become reflective practitioners, illustrating how this spiral of reflection could work in a school setting. During staff meetings, teachers had the opportunity to think about how to use what they learned in their classroom. Then the administration followed up on those goals using classroom observations and interviews with teachers, based on evidence they collected from the students. The framework provided elements for reflection and could also be used during the individual teachers’ lesson planning.

Thus, experiences of metacognition involving the whole school or district could help teachers develop conscious reflection about their teaching (informed and critical)
because they involved several of the indicators in these two levels, such as the use of evidence, an attitude toward improvement, theory to inform teaching, or criticism. I compared the spiral of reflection described by each participant with the level of reflection that I ascribed after analyzing the interviews (Table 4.20 and Figure 4.9). I observed that often the reflections I classified as CCR came from teachers participating in a school-wide reflective practice, as was the case with Matt, Jean, and Lucy, but not for Pam and Henry. In fact, in the classification of level of reflection, Henry was in the lower level (UR). As a result, I decided to give Henry and Pam’s cases a closer examination.

Table 4.20

<table>
<thead>
<tr>
<th>Reflective practice</th>
<th>Unconscious reflection</th>
<th>Conscious informed reflection</th>
<th>Conscious critical reflection</th>
</tr>
</thead>
<tbody>
<tr>
<td>School-wide</td>
<td>Henry</td>
<td>Pam</td>
<td>Lucy/Jean/Matt</td>
</tr>
<tr>
<td>Small group</td>
<td>Paula</td>
<td>Gina/Kate</td>
<td>Betty</td>
</tr>
<tr>
<td>With a mentor or a partner</td>
<td>David</td>
<td>Frank/Steve</td>
<td>Emma/Elsa</td>
</tr>
<tr>
<td>Individual</td>
<td>Mary</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Arrows show shift form level of reflection during interviews.*

I classified Henry’s interview as unconscious reflection because he described his metacognitive teaching style as a “transmitter of knowledge” and often made generalizations about his students. When Henry described his teaching, he was frequently focused on direct instruction, learning accountability, and informal practices. As he explained: “*I’ve mostly tried to point out things they’ve learned in other classes. And say: ‘look, you guys have this background knowledge, don’t just store it, you know, apply it’*” (Henry interview, line 40). Henry described “pointing out” to students what they learned, instead of letting them come up with their own conclusions.
He also used generalizations: “So, if you ask why to one person in a class of twenty, that... when they’re sitting there thinking you have about 10 seconds before everybody else’s brains switch into something else” (Henry interview, line 50). Here Henry explained that metacognitive practices were difficult because students could not wait for an answer and “switched their brains into something else.” Although I agree teenagers’ attention span can be short, Henry’s reflection only considered students’ limitations and not the effectiveness of the strategy or his role in promoting reflection.

Figure 4.9 Participants’ levels of reflection and spiral of reflection. Numbers represent the number of teachers at the correspondent level. School-wide reflection had three CCR interviews, and two more I described as moving forward (Henry and Pam).

Based on the quantitative analysis of Henry’s interview, 52% of his coded segments were unconscious reflection, 36% were ICR, and 12% were CCR. During our conversation he also showed concern about accountability for learning and using data and experiences to inform his teaching. For example, he stated: “And, that is handy for me to see... ‘wow, this problem was commonly missed.’ Highlight the problems that were...
commonly missed” (Henry interview, line 54). Henry described at several opportunities how he used experience and data to inform his teaching, as when he was assessing a test and reflecting on how a problem was commonly missed. Thus, his reflection was not completely unconscious.

Moreover, I had worked with Henry as part of the larger research project on which I was collaborating. He had always been open to learning, and we had excellent conversations about his teaching and elements that he could improve. I would classify Henry as a reflective practitioner. In fact, he was the first teacher who agreed to participate in my study, and after thanking him for his participation he told me he always learned something from our conversations. That attitude seems more aligned with CCR than with UR.

After thinking and checking my coding, I concluded that Henry had an exemplary experience of metacognition, participating in all levels of the spiral of reflection about his teaching. I also observed Henry was using evidence and experiences to support his teaching and an open attitude toward learning and reflection. Moreover, he had been teaching physical science for several years. Therefore, based on his answers about his metacognitive practices, he might not have a clear understanding of how to use complex metacognitive teaching in his classroom. Instead, he focused his description and reflection on teacher-centered practices and generalizations about students’ thinking. Henry’s lack of pedagogical knowledge about using metacognition could be related to his simpler level of reflection during our conversation.

Like Henry, Pam was also participating in a school wide PD (using Marzano’s framework for teaching) and involved in all levels of the spiral of reflection, although her
level of reflection was CIR rather than CCR. Pam was in her second year of teaching, but still dealing with first-year teacher problems. At the time of our interview she was preparing at least four new courses outside her field of expertise.

The latter was also true in Betty’s case, and I classified her reflection after the interview as CCR. Betty had four years of teaching experience but was teaching chemistry for the first time (and out-of-field as well). She stated, for example: “I mean I really, for chemistry I’m just taking it day-by-day because I have no idea what I’m doing and I’m just going” (Betty interview, line 128). This is an example of the indicator “getting things done for now” of UR. I was familiar with Betty’s teaching skills and openness to learning, as she was a participant in the larger research study. However, when she talked about teaching chemistry for the first time, she reflected using UR.

On the other hand, Matt, Jean, and Lucy had been teaching the same course for at least four years in-field. Outside of their teaching experience, openness for learning, and personal characteristics that could influence them, the spiral of reflection could provide them with effective support.

Therefore, the spiral of reflection might have some influence on teachers’ level of reflection. However, reflection is a complex construct and other elements can affect experiences of metacognition as well. In addition to registering experiences or openness to learning, years teaching the same course and pedagogical knowledge can also affect teachers’ experiences of metacognition.
Research Question #4:

What Knowledge and Experience of Metacognition Affect Teachers’ Instructional Practices of Metacognition (or Metacognitive Teaching)?

For this study, I explored beginning science teachers’ knowledge and practices of metacognition using a survey, open-ended interviews, and classroom observations to collect data. I coded those interviews to analyze the information and explore the answers to my research questions. I present a summary of findings in Table 4.21. I highlighted teachers who were frequently using metacognitive practices.

Table 4.21

Summary of Participants’ Data

<table>
<thead>
<tr>
<th>Participant</th>
<th>Gender</th>
<th>HS/MS</th>
<th>Years of exp.</th>
<th>School SES</th>
<th>MAT/UG</th>
<th>MAIT score M (SD)</th>
<th>Type*</th>
<th>Spiral</th>
<th>Teaching MG**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paula</td>
<td>F</td>
<td>HS</td>
<td>0</td>
<td>Low</td>
<td>MAT</td>
<td>3.5 (0.7)</td>
<td>UR</td>
<td>Group</td>
<td>TAIi</td>
</tr>
<tr>
<td>Elsa</td>
<td>F</td>
<td>HS</td>
<td>1</td>
<td>High</td>
<td>MAT</td>
<td>3.9 (0.3)</td>
<td>CIR</td>
<td>Peer</td>
<td>TSI</td>
</tr>
<tr>
<td>Frank</td>
<td>M</td>
<td>HS</td>
<td>1</td>
<td>Low</td>
<td>MAT</td>
<td>4.0 (0.6)</td>
<td>CIR</td>
<td>School</td>
<td>SSFg</td>
</tr>
<tr>
<td>Gina</td>
<td>F</td>
<td>HS</td>
<td>1</td>
<td>High</td>
<td>UG</td>
<td>4.3 (0.6)</td>
<td>CIR</td>
<td>Group</td>
<td>TAIi</td>
</tr>
<tr>
<td>Kate</td>
<td>F</td>
<td>HS</td>
<td>1</td>
<td>Low</td>
<td>UG</td>
<td>3.9 (0.7)</td>
<td>CIR</td>
<td>Group</td>
<td>TAIi</td>
</tr>
<tr>
<td>Lucy</td>
<td>F</td>
<td>MS</td>
<td>1</td>
<td>Low</td>
<td>MAT</td>
<td>3.5 (0.6)</td>
<td>CCR</td>
<td>School</td>
<td>SSFi</td>
</tr>
<tr>
<td>Pam</td>
<td>F</td>
<td>HS</td>
<td>1</td>
<td>High</td>
<td>MAT</td>
<td>3.3 (0.9)</td>
<td>CIR</td>
<td>School</td>
<td>TAIi</td>
</tr>
<tr>
<td>Steve</td>
<td>M</td>
<td>HS</td>
<td>1</td>
<td>Low</td>
<td>MAT</td>
<td>4.3 (0.7)</td>
<td>CIR</td>
<td>Peer</td>
<td>TAIi</td>
</tr>
<tr>
<td>Henry</td>
<td>M</td>
<td>HS</td>
<td>2</td>
<td>High</td>
<td>MAT</td>
<td>3.5 (0.7)</td>
<td>UR</td>
<td>School</td>
<td>TAIi</td>
</tr>
<tr>
<td>David</td>
<td>M</td>
<td>HS</td>
<td>3</td>
<td>High</td>
<td>MAT</td>
<td>4.3 (0.8)</td>
<td>UR</td>
<td>Ind.</td>
<td>TAIi</td>
</tr>
<tr>
<td>Emma</td>
<td>F</td>
<td>MS</td>
<td>3</td>
<td>Low</td>
<td>MAT</td>
<td>-</td>
<td>CCR</td>
<td>Peer</td>
<td>TAIi</td>
</tr>
<tr>
<td>Betty</td>
<td>F</td>
<td>HS</td>
<td>4</td>
<td>Low</td>
<td>MAT</td>
<td>3.8 (0.4)</td>
<td>CCR</td>
<td>Group</td>
<td>TAFi</td>
</tr>
<tr>
<td>Jean</td>
<td>F</td>
<td>HS</td>
<td>4</td>
<td>Low</td>
<td>MAT</td>
<td>3.9 (0.3)</td>
<td>CCR</td>
<td>School</td>
<td>TAIi</td>
</tr>
<tr>
<td>Matt</td>
<td>M</td>
<td>MS</td>
<td>4</td>
<td>High</td>
<td>MAT</td>
<td>4.2 (0.7)</td>
<td>CCR</td>
<td>School</td>
<td>TAFi</td>
</tr>
<tr>
<td>Mary</td>
<td>F</td>
<td>Both</td>
<td>4</td>
<td>High</td>
<td>MAT</td>
<td>4.0 (0.7)</td>
<td>UR</td>
<td>Ind.</td>
<td>SSFi</td>
</tr>
</tbody>
</table>

* CCR → Conscious critical reflection; CIR → Conscious informed reflection; UR → Unconscious reflection
** T → Teacher questioning; S → Students’ own questions; A → Accountability of learning; S → Thinking as a scientist; F → Formal (written learning outcome); I → Informal (no written learning outcome); i → individual; g → group.

Mary: Impacting Students’ Learning Through Reflective Questions

Mary was a fifth-year middle school and high school science teacher and was part of the first cohort of the MAT program. She had been teaching at a private Catholic school in a small Midwestern city since graduating from her TEP, making the 2016-2017
school year her fifth year of teaching. I had observed Mary’s lessons for at least four years as part of the larger research study. When I conducted this study, she was teaching four different courses: two sections of sixth grade general science, two sections of seventh grade life science, one section of sophomore biology, and one section of biology 2, which she described it as a dual credit course (i.e., students could receive credit for both high school and college). None of these courses was new for her. Mary’s school normally had 46-minute class periods, although on Fridays they shortened to around forty minutes. Mary was teaching six out of eight periods every day.

Mary originally attended college because she wanted to become a science researcher, pursuing a biology major with an environmental studies emphasis. She realized she had a special interest in ecology during her undergraduate studies and began working on a few different research projects related to this area. She said that conducting and presenting these projects gave her a sense of what a researcher does: “As an undergrad I went and presented it for a couple different things, absolutely adored it, doing the research, that kind of thing” (Mary interview, line 29). Mary also worked as a teacher naturalist at a local park during college. After that experience, she realized she wanted to become a science teacher.

Mary was in her late twenties at the time of this study and was a mother to three children. I wanted to interview her for this project but knew she was busy. When I asked, she proposed we conduct the interview via phone during her drive home after teaching. After Mary’s description of metacognitive teaching, I thought what she was doing was exemplary. I asked if I could visit her classroom for two weeks after acquiring school approval, and she agreed.
I visited Mary’s classes from January 23rd to February 8th, 2017. In total, I visited 424 minutes of instruction during three weeks. Mary incorporated different instructional activities during those days: lectures, a student research project, a simulation, and a modeling activity. The topic was astronomy, and the lessons covered the phases of the moon, the solar system, and constellations.

I observed Mary’s second section of sixth-graders during the 7th period of her school day. She had nine students in that group: three male and six female. Two of the students were Latino and the rest White or Caucasian. Each day Mary welcomed the students with a slide projecting the agenda for the day, the material they were going to need (e.g., textbook, notebook, specific worksheet) and an opening question to answer. This opening question was often related with what students did during the previous class. The students all had iPads and answered the opening question online. After those first minutes, Mary asked students to stand up and read aloud a short prayer in Latin. Mary told me she liked to pray in Latin because it helped students understand certain scientific terms or topics, like the dichotomous key. After the prayer, Mary discussed the opening questions with students and read the agenda for the day.

During the first session I observed for this project, Mary showed a video, discussion questions, and a presentation about the phases of the moon and eclipses. At the end of the presentation, she made comments and showed pictures of the red or blood moon. She explained students could use ideas like that one for their reflective questions. Then, about ten minutes before the period ended, Mary gave the students the instruction to write reflective questions.
The reflective questions consisted of two parts. After the lecture, which included a Power Point presentation and class discussion, Mary asked students to write a few sentences in their science notebooks about what they learned or things that surprised them about the information she presented. After this individual activity, students had to come up with two reflective questions. Students then, individually, answered their questions on their iPads. Mary expected they would write at least a few sentences in response to their questions.

As an example, on one of my observation days (January 24th, 2017), the lesson was about the phases of the moon. After Mary finished her presentation and class discussion, students worked on their reflective questions in their journals for the last ten minutes of class. For those who did not finish, Mary told them it was part of their homework. Sometimes when she was presenting on a topic, Mary gave students ideas about reflective questions they could ask. Additionally, when students began asking questions, she sometimes responded with “that would be a good reflective question.” For example, on January 26th, while she was explaining the asteroid belt, Mary mentioned to students that they could think of reflective questions related to the belt when they asked about this part of the solar system.

During my eleven visits to her classroom, Mary conducted the same exercise at least twice (once with the phases of the moon, and the second time after her solar system presentation).

I also observed students engaged in the reflection activity. For instance, on January 24th, I wrote in my memo: [during the reflection time] “I like to observe [Mary] smiling and expressions from the students like ‘wow!’ They are interested and working
on their questions” (Mary Field notes Jan 24th, 2017). I observed students working on their questions, writing, and looking for answers using their iPads. I also observed Mary smiling as she watched students work, seemingly expressing satisfaction or accomplishment.

Moreover, I noticed students were more active during Mary’s presentations than in regular classrooms during a lecture, coming up with several questions and even sometimes with their own answers. For example, on Jan 30th, Mary taught a lesson about the solar system. She showed a picture of Jupiter and explained the planet has a permanent storm as big as the Earth. A minute later, one of the students (a boy) showed a picture on his iPad of Jupiter comparing the storm with Earth. While Mary was explaining, he had looked for the picture on the Internet. I wrote that day: “I like that the students come up with questions and they find their answers. Like B3, who was curious about the storm in Jupiter and he looked for the image comparing the Earth with that storm. I think the students are motivated to learn, they like to ask questions and find their answers” (Mary Field notes Jan 30th, 2017). I understand other elements could have influenced this behavior, such as the students’ age, the number of students in the classroom, their contexts or backgrounds, and their interest in the topic, to name a few factors. Nevertheless, I have been in other classrooms under similar conditions and have never seen students participating in class to that extent, looking for information to support the teacher’s explanation.

Mary told students during my second week of classroom observations that they needed to turn in their notebooks for grading on that Friday. She gave them a list of
activities and reflections they were supposed to have in their sciences notebooks. The following class, Mary handed back the notebooks.

I talked with Mary before class that day and asked her how she graded the notebooks, which she checked every quarter. She told me this was her 4th check this year and showed me the rubric she used at the back of one of the students’ journals. Mary gave students this rubric at the beginning of the school year. It included five criteria: the context, which was the format of the notebook (e.g., date, page number, place, etc.), the data collection (e.g., how to present charts and tables, qualitative and quantitative data), drawings and labels, lab questions, and reflections.

For this last criterion, reflections, she provided writing prompts (e.g., “I used to think _____, but now I think _____,” or “The most important thing to remember about ____ is ____”) (Appendix S). She also described the reflective questions as “two questions that connect to the activity or current unit.” Mary used the concept of metacognition as finding connections between topics and ideas. She explained how she checked whether students had written their two sentences and answered their questions to consider that criterion as completed. She noted it took a lot of time to grade these reflections, and she had developed a “sense” of what a good reflection should be. The rubric helped, but Mary graded more based on her experience after doing this activity for four years. The entire activity, including the five criteria, was 40% of the students’ grade for that quarter.

On Tuesday, February 7th, when Mary returned the graded notebooks, she gave students feedback on how to write their reflective questions and answers. For example, she reminded them about the importance of including the reference from the site where
they found the information (although this was not part of the criteria on the rubric) and writing at least two sentences. It seemed that after several times doing these reflections, she included the reference part to improve students’ reflections as part of their learning process.

This was the most sophisticated practice I found among the study participants. Using my classification, I considered this to be a student-generated, thinking as a scientist, accountability for learning, formal, individual metacognitive teaching practice. It was student-generated because students were thinking about questions they wanted to ask about the topic, generating their own questions and finding their own answers. It fulfilled the thinking as a scientist purpose because on a small scale students were using the NGSS scientific practice #1, asking questions (for science) and #3, carrying out investigations. It also included accountability for learning because students had to provide a few sentences summarizing their learning. It was formal because there was a clear student outcome, and the teacher could grade it and provide feedback to help students improve. Finally, this practice was individual because each student came up with their own reflective questions. If Mary wanted to improve this practice, based on the diagram I developed for teaching metacognitive practices, she could also include an aspect of collaboration.

Mary said she used the reflective journals when she first began teaching, refining and improving them after she gained experience using them with her 6th and 7th graders. When I asked when she started using this strategy, she answered:

*Since the beginning. I wasn’t as good my first couple of years because it takes some grading to do the journals, to do all that takes a lot of time for me but I’ve*
gotten better and better about it so giving them the prompts and that kind of stuff to help them get started at the beginning has really helped. So, I’ve always had it kind of in there. (Mary interview, line 196)

Based on this explanation, the main challenge seemed to be finding the best way to grade the reflections. Mary explained she included prompts to help students summarize their learning, which were especially important at the beginning of the school year. By now, students knew what she expected them to do. Mary’s experience using this strategy helped her improve and adapt it to students’ needs. On the other hand, practice was also important for students to understand what they needed to do. As Mary explained:

Yes, I do grade them. It takes some knowledge of what the student’s level is, whether it’s a good reflection or not because you have different levels of learners. So, I can kind of tell after I get a feel from the students and kind of know what to expect out of them. I do grade, mine is more of a length thing, two sentences, which kind of pushes them too. (Mary interview, line 192)

Mary described how experience helped her discern the level of reflections students could write. She felt pushing them to write at least two sentences was a good challenge.

Later, when discussing students’ experiences with the reflective notebooks during her interview, Mary noted:

They kind of disdain it and they don’t like it for a while because it’s hard. It’s not easy and it’s pushing them outside of their comfort zone in ways. By the end of the year or by the end of the first quarter even they’ve got it kind of figured out ...

... They don’t, they don’t enjoy it because it’s not easy and it pushes them to
think a little bit harder and to think in a different way than they’re used to so that’s kind of the general reaction to it (Mary interview, line 188).

Mary believed students did not like these reflections because they were difficult and challenging. However, she noted that prompts helped, as did practicing throughout the year. As an observer, I saw students engaged and working on their reflections, and I never saw or heard any complaints or commentaries against the strategy.

For the last of Mary’s classes I observed, since I had asked the day before whether she knew how students felt about the reflections, she asked them to rate their feelings. She told them to put their heads down so they would not be influenced by others’ answers and to answer with one hand, on a scale of one to five, three questions about the reflection activity (Mary Field notes February 8, 2017). Mary asked them how they felt about their reflection journals, how much they liked or disliked them, and how much they learned. Students mostly answered 4s for how much they had learned, and two students gave a 5. Most students gave 3s and 4s in the like or dislike question. Mary seemed content with students’ answers at the end of this quick survey.

When I asked Mary how she came up with this strategy, she said she took a geology course during her undergraduate studies and learned it there:

*I took that geology, like 150, with Dr. [Last Name]. It’s a, I don’t know if you’ve heard about that class, it goes to Wyoming kind of area and is an inquiry-based geology course for educators. A really great program that kind of I model some of my journaling off of. It’s one of the classes that I learned the most out of my whole entire college career, like one of the things that I retained the most, so I
realize that if I retain it the most then other kids will retain the most with that kind of teaching style, in a way. (Mary interview)

It seemed that Mary not only learned from but also enjoyed her time in this geology course, calling her studies “a really great program.” She considered this the source of most of her content knowledge and learning during her undergraduate education. She was thus using her experience as a student in this course to inform her teaching. The professor modeled using a metacognitive practice embedded in the science content, which Mary then used from the beginning of her own class.

Finally, I asked whether Mary used this strategy in the same way with all her students, biology included. I wrote in my memo that day: “I asked her if she does the same thing with her older students. She told me she does not use it with her honors students because they may start joking about reflective questions and the course is more content-oriented. Mary said older students do not like to reflect” (Mary Field notes, January 31st, 2017). Mary explained these reflections took time and she preferred to use them with her older students to focus on content. This concurs with what the research group observed, as high school lessons had lower percentages of student reflection than middle school lessons. Thus, Mary was not using reflective questions with high school students because she needed to focus on the biology content. She explained high school students did not like to reflect and she was afraid they would make jokes about her or her lessons based on the use of reflective questions. She was clearly concerned about building positive relationships with her students.

After coding I classified Mary’s interview as UR, a surprise for me. She had a 4.0 (SD=0.7) in her metacognitive awareness survey, which meant she had a solid awareness
of her knowledge of metacognition and was using an exemplary reflective teaching practice. As a result, I was expecting her to have a higher level of reflective practices. I was also surprised because I had worked with Mary in the larger research study, and she was always open to learning and research. I thus tried to analyze what could have happened.

I checked Mary’s coded segments to see if I made a mistake. I noticed she used some generalizations or unsubstantiated claims like she did in the previous excerpt, saying students would make jokes about her. I do not know whether this was a personal concern or derived from students’ evaluations of teachers, but I noticed Mary was preoccupied with what students thought about her. Again, I wondered whether the scale I used for these levels of reflection was not missing one more level related to the affective dimension of reflection and teaching, which is after all an important aspect. I also think the context for our interview might have affected Mary’s level of reflection, as explained previously. Moreover, in the spiral of reflection, Mary said she felt she was working alone and rarely received feedback or opportunities to reflect with other teachers. She also had a busy schedule, teaching four different courses that lasted almost the entire day. Thus, these could also be factors that affected Mary’s level of reflection.

In sum, then, Mary learned this strategy, classified as accountability of learning/thinking as a scientist, formal, student-generated, and individual, in a geology for educators’ course during her undergraduate degree. The main improvement she applied over time was gaining a better understanding of how to grade these reflections and what to expect from students. This was an example of overcoming ideas of reflection as something “personal” that cannot be graded. It also seemed to support the importance
of using learning outcomes. These written reflections allowed Mary to provide feedback on how to improve students’ summaries, reflective questions, and answers. Her students were learning and practicing how to come up with their own questions and find their own answers. The strategy thus appeared to support students in becoming independent lifelong learners.

Mary began using reflective questions at the beginning of her teaching career, but also improved them after some iterations. For example, she added the writing prompts after she had a better sense of the kind of reflections students could write for grading purposes. Experience thus helped her adapt this strategy to students’ and the course’s needs. Hopefully in the future Mary could continue to improve this exercise, such as adding a collaborative or communication component as well as adapting it to the content demands and conditions of older students.

However, it seemed that what helped Mary the most was observing and using the strategy herself as a student. Her professor modeled how to use this strategy embedded in science content. Mary thus realized the impact of this lesson on her own learning and decided to use it as part of her teaching. Although it took time and effort for her and her students, she considered this practice important, finding it helpful in building positive relationships with her younger students and having an impact on their lives.

**Frank: Developing Engineering Minds.**

Frank was a second-year teacher in his early twenties. He studied physics and mathematics, minoring in religious studies. Frank said he had had several teaching experiences during his undergraduate major, while working in summer camps, and as a teacher assistant:
I taught some introductory physics and calculus. Recitations of labs and I also was a summer camp counselor for a summer a missionary course summer where I did a little bit of step for children and teaching children over there and then another summer I was an intern at Massachusetts Institute of Technology where we were hosting science summer camps and they brought in physics majors and we're teaching as a pedagogy of how to like teach middle and high school students. (Frank interview)

After multiple summer camps as well as teaching introductory physics and calculus courses, Frank decided to start the MAT program.

He also told me it was important for him to impact students’ lives. The first time a summer student thanked Frank for caring about him, Frank in that moment realized how important teachers could be to students:

“Mister, I just want to thank you because you're one of the first persons that really show that they care about me.” And, I was like “I don't even know your name kid” like “I don't know where you from,” I think he was from [Midwestern city], “I don't know what you're doing here, I don't know who you are...” they at that like... hour and a half two hours I had them doing some outdoor adventure activities with you and this possible impact and so I was like “am I leading to be like that? Oh yeah! I impacted this kid.” (Frank interview, line 19)

Frank was moved by this event and knew he wanted to be a teacher based on students’ need to feel cared for by others.

During his student teaching, Frank’s cooperating teacher told him about a new project in the district and said they were looking for an engineering teacher. Frank was
hired at this new vocational academy, a project between the school district of a Midwestern city and a community college, and had taught there ever since. The academy offered sixteen different professional pathways as elective courses to high school students from the district. Frank was teaching the engineering course there, along with physics courses at the community college.

The engineering pathway took two years to complete. Frank had mostly the same students for both years, as long as they decided to stay in the academy and finish the pathway. Students could also drop out of the program at any time after each term, or start a new pathway.

The school had opened only two years prior to the study, so the facilities, located next to the community college, looked new and designed to fulfill each pathway’s needs. Frank received students from all of the public (and some private) high schools around the city. For the first class period, from 8:15 AM to 10:15 AM, students arrived via school bus or their own cars. After class ended, they returned to their high schools to take the rest of their regular courses. Then, around noon, new students came to take the vocational classes after spending the morning in their original high schools. In Frank’s case, his first period was mostly for juniors and the second period was for seniors.

The curriculum, materials, and activities for Frank’s engineering classes were based on a nationwide organization that promotes science and engineering programs using project-based learning. Frank told me he took a few courses during the summer to prepare for teaching, as well as learning some other skills (e.g., using the programming language Robot C) (Frank Field notes, November 16th, 2016). In fact, this organization sent the final test for his engineering courses. He did not know exactly what would be on
that test, but he had the curriculum and the projects students needed to do. As Frank explained:

"[Name of the project] gives me the curriculum and says: “modify it to fit your needs.” But, here's the curriculum that the standardized final beyond and so like my first year going through the course I was like “okay, I'll just kind of do it like they want me to, find out what works well and what needs to be changed.”

Now, the second year of the principles of engineering course I'm making all the microscopic changes to make all the activities easy or more straight line and better for the students to get to their understanding I need them to get to. (Frank interview, line 81)

Frank had the flexibility to make some changes to adapt curriculum to students’ needs. He could also change the percentages of the assignments and the weight of the test in students’ final grade. He explained in the previous excerpt that the first time he taught the course he decided to do exactly what he was told in his PD. During his second year, he started implementing small changes and adapting it based on his experience the prior year. Then, he developed a systematic register of all the documents he was using and the slides he presented in class. He also numbered each lesson to identify them and replicate them next year.

Frank’s course I observed was principles of engineering, the first course for students in the engineering pathway. I visited at the end of the term, from November 10th to December 2nd, 2016. Frank taught in a large classroom with a storage room at the back and a laptop cart. On the left side of the room Frank kept a tall cabinet with materials. He also had boxes with materials at the front of the classroom. The class was set up with
three tall tables and chairs organized in stations. The room had one large white board at
the front, one on the right side, and space for writing on the walls on the left. Frank also
used a computer and a projector at the front of the room.

Each day, students picked up a computer and went to the storage room to take out
their materials or the test bed with their robot in process. Frank had 23 students in this
class: four female and 19 male. Students sat in assigned seats with their group members
in groups of three and started working together on the previous project. Frank explained
he randomly formed the groups using a program, then made some “executive decisions”
to make the groups work better (Frank Field notes, November 17th, 2016). He was trying
this new form of grouping students, although in the past he had let students form their
own groups.

During my first classroom observation, students took a test and Frank introduced
the project they were going to work on until the end of the semester. This was their third
project. Frank projected a document at the front of the room with a brief description and a
rubric to explain what students needed to do (Appendix T). He told me he could share
that document with the students, although he gave out printed copies in class. Frank
explained students were familiar with this rubric because it was the third time they were
using it. This project was about building a robot designed for commercial purposes and
taking care of safety issues. Students needed to develop the programing code using a
language called Robot C and build the robot, which they would present in December to
their parents, other students, and academy support teams. This project was 20% of their
final grade.
Frank also explained that he graded students on their process and not just the product:

…but, we grade on process so as long as they documented what their design was and they got their questions, have to write a brief to get approval for the project so I can manage supplies and they document it how they built it and how well it worked or didn't work but if they did all of that stuff, they get a really good score on it because one thing the students don't necessary know is a failed project is still a good result for us in the real world, right? (Frank interview, line 161)

Frank valued how these projects were focused on the processes students needed to develop in order to create robots, for example. The engineering notebook was useful for documenting the process, as he included questions to help students reflect on their work, and all of these criteria were part of the course assessment.

Frank also had well-developed routines for his lessons. After about five minutes, Frank rang a bell to call students’ attention and talked about announcements, goals, and materials needed. For the announcements, he included the due date for the current project, the dates for presentations, and other information important to the class. For example, at one point Frank issued an invitation for students to participate in an engineering competition, while another time he discussed logistics related to staying in the engineering pathway and registering for courses next semester.

After the announcements, Frank projected a new slide with goals for the class period. Each class he demonstrated what students should accomplish in order to make progress on their project and finish by the established date. However, it was not an issue if groups were ahead or behind on those goals, as they were simply a reminder for
students to know where they should be at that point in time. Frank also included information about the coding or details that were important for the project, such as including comments in the coding or taking pictures of their work. Next, students worked in their groups for the rest of the period while Frank circulated, talked with them, asked questions, and gave feedback on their work. Sometimes a group of students went to one of the boards and started writing codes and drawing their projects, talking with Frank about a problem they were having trouble solving. Frank was there to ask questions and help them figure out their answers.

The environment of the class felt very relaxed and flexible. Students could eat, drink, or leave the classroom at any time. They could also test their robots outside without consulting Frank. Students went freely to the storage room, obtained the material they needed, and worked at their own pace. When they had questions, for example about a piece of material they needed, Frank was always there to help. It seemed students were responsible for their actions and decisions, while Frank was focused on helping groups develop their projects. Moreover, sometimes while Frank was busy, other students helped each other or went to observe other groups’ projects, asking questions and starting discussions. It was amazing to observe them working together. Occasionally, students were off task or playing with the material and laughing, but after a few minutes, they always went back to work.

Five minutes before class ended, Frank projected a new slide with instructions for finishing the day, such as cleaning up the space and leaving test beds in the storage room. Students knew what they needed to do, and the classroom was always clean after they left.
Frank gave a list of possible ideas and showed some videos to the students at the beginning so they could choose from those ideas or come up with their own. During the first class, students designed projects individually and discussed which project was most feasible within the group. They had to build a decision matrix to evaluate each student’s ideas and select the best project. Next, they had to come up with group norms for how they wanted to work together. Frank had shown them examples earlier in that term with their first project, so they knew what sort of norms they needed to establish. All of those decisions also needed to be recorded in their engineer’s notebook. Although they were developing a group project, each student had to fill out their individual notebook with all the steps of the engineering process, which was the first major reflective piece of the project.

After choosing the project they wanted to work on, students had to ask Frank to approve their idea. He asked questions to verify their plan, examined their decision matrix, and checked whether it was possible to complete the project they selected (especially based on the time and materials needed). If the project was too simple, he could also ask the group to revise it.

Students had six periods of two hours each to finish their projects. Because not all students worked at the same pace, some finished their projects ahead of time. In those cases, Frank approached the groups and asked how they might improve their design, encouraging them to incorporate those improvements.

Since the beginning of his participation in the study, Frank told me he used the word “reflection” more frequently than “metacognition.” For him, reflection was also a fundamental part of these projects. The rubric included asking students to write down an
evaluation of the project, as well as answering questions (Appendix T) about the challenges, limitations, how to improve their robot, and the cost of materials. As Frank explained, “It’s funny because I think many of the students see it as being like kind of annoying item they have to do” (Frank interview, line 115). This was the second reflective piece during this project.

However, students also had to think about how to improve their projects constantly or solve the problems they faced while they were building their robots. In Frank’s words, “…while they’re doing the project [the students] reflect all the time without even knowing it. Cause they’ll build something and if it doesn’t work and so without even knowing it they reflect upon ‘okay what can we... how can we fix this? How could we make this work?’ Like they’re doing it all the time” (Frank interview, line 125). Frank explained how during the entire process, students were thinking about how to solve problems even when they did not notice it. Frank was convinced of the importance of this methodology and the role of reflection during the engineering process.

During the last class session, students presented their projects to their classmates to practice what they were going to say in the evening exhibition. Frank gave them a card to provide suggestions to the presenters about how to improve their project. Students were also required to turn in their engineering notebooks and assess their group members (Table 4.21), the third major reflective piece of the project.

The rubric also included a reflection after the expo presentations, but I was not able to observe how this worked. Besides the project, during my time observing, Frank asked students to turn in a reflection about a branch of engineering they liked and how this course was helping them (or not helping them) make decisions about their future
careers. Additionally, Frank explained that students had to develop four professional skills (e.g., effective communication) that the school set up based on the state standards. Every quarter they filled out a rubric and compared their grades with their skills performance. Frank described how he used these skills evaluations:

*We have the assessments I mentioned before, the evaluation pieces. So, we have those and they evaluate, I evaluate, and every time we actually have sort of teaching conferences if you will and we look over those evaluations and for... and we keep those in storage for posterity’s sake. But, for most of our students, how I evaluate them and how they evaluate themselves are semi-[inaudible] with each other. If there’s is a very strong distinction between the two then I have a one-on-one time with the students. Like I had once a student who was like “Oh, yeah! I am doing excellent to all of these.” And I was like “no, you’re not. You are barely meeting half of these, if at all.” And, he was the one who was failing my class. And, I see the failing grade that indicates to me, okay, at least, how they tune these for standards are being matched. He thinks he is meeting them but I think he is not meeting them. And that's when I end up having an individual conversation.* (Frank interview, line 45)

Frank explained he used a rubric with these four skills to assess each student, as well as letting them self-assess. He was convinced this skills evaluation was correlated with students’ achievement in class. He considered the evaluations a tool to promote individual reflection and used them to have conversations when his assessment and the students’ self-assessment did not concur. He also explained he kept a record of these evaluations for “posterity’s sake.” Frank often taught the same students for two years, so
this was a way to keep records about their growth. He also noted these skills were promoted throughout the academy, and the school administrator asked teachers to set up goals based on how to develop these skills. Therefore, as with the spiral of reflection, Frank was participating in a school-wide reflection.

Finally, when I asked Frank whether he used this reflective methodology in his other courses (i.e., physics), he said he did not. He told me his physics course was more content-oriented and did not use projects.

Frank, who was in his second year as teacher, also had a 4.0 (SD=0.6) on the MAIT survey, which meant he had awareness of metacognition as a teacher. I considered his project-based reflective practices exemplary and unique metacognitive teaching because he was the only teacher among the participants who described collaboration and group work as part of reflective practices. Although each student had to write their own engineering notebook for his class, the reflection, based on a “tangible” product (i.e., the robot), usually took place after a discussion and collaboration within the group of students. The students worked together to come up with an idea, solve problems, and evaluate the process. Therefore, I classified this practice as: thinking as scientist (or as an engineer, in this case) because it was about applying and assessing the engineering process to develop a project; formal, because students had to record every part of the process in their engineering notebook and include at least three reflective pieces as part of the project assessment; and student-generated, because although the teacher included questions for students to answer in the rubric, they also had to set up their own group norms and use them as evaluation criteria.
During his interview, Frank expressed a strong orientation toward CIR. He used experience and data to support his teaching, talking about “tangible” goals and keeping a record of his students’ performance for “posterity” purposes. He was meticulous in recording the documents and slides for each of his lessons, and he considered his experience a valuable tool for improving his teaching.

Reflection was also an important piece of Frank’s teaching. Besides his TEP, he learned how to use reflection in his engineering classroom during the professional development he received from a nationwide organization. He was also part of a school-wide reflection, using the four skills promoted as part of the academy. The entire school was working on the same skills, and the administration was part of these efforts.

In sum, Frank was involved in a rich and reflective environment as a teacher. He understood the importance of reflection as part of a learning process. However, it appeared that the most influential element in Frank’s use of reflective teaching practices was learning from the professional development he received in preparation for the engineering pathway.

In conclusion, I found that in these two smaller cases, both Mary and Frank experienced someone modeling metacognitive teaching practices embedded in science content. Mary’s modeling occurred in an undergraduate geology course, while Frank learned from the professional development he received before teaching in his program. However, neither participant was using reflective practices in all of their courses. Mary used metacognitive teaching practices for her 6th grade science course, but she was not using reflective questions with her high school biology students. Likewise, Frank was using reflective practices with his engineering pathway students because the design of
this course included that aspect as an important element of the engineering process. However, he was not using them with his physics students. This concurs with the conclusion after classroom observations that it is more common to find metacognitive teaching practices in non-traditional or elective courses (e.g., principles of engineering) or in middle school courses (e.g., 6th grade science) than in traditional (e.g., biology, chemistry, ESS, physics) high school courses.

**Summary of Findings Related to Research Question #4**

In sum, teaching experience was the strongest variable that seemed to influence teachers’ metacognitive awareness in this study. Participants had a strong awareness of metacognition for their practice and could identify the traditional definition of metacognition. Nevertheless, they were hesitant when they explained what “thinking about thinking” meant for them. They studied and used metacognition during their teacher education programs, but the majority did not hear the term again, either in the schools where they taught or in any other setting. Almost all participants focused their attention on the psychological elements of metacognition. Teachers related metacognition with learning, assessment, connections, and especially with reflection. Not as common, but also present, was the epistemological nature of metacognition. Participants often understood metacognition as a necessary element to develop thinking as a scientist, but they did not clearly understand how. For instance, they could identify metacognition as thinking about data to generate conclusions after a lab activity, or coming up with questions about information in a science classroom or the messages we find in society. However, they often understood metacognition as re-thinking, as a double cycle of thinking over the same ideas. Their understanding in this area could be expanded.
Participants also preferred to use the word “reflection” to describe thinking about learning. There were no substantial differences between their descriptions of these two terms (i.e., metacognition and reflection). Metacognition seemed to them a more complicated or abstract construct related with thinking. Reflection, in comparison, seemed to be a more accessible and easily understood concept.

Moreover, participants held some misconceptions about metacognition. Most of them related to the difficulty of apprehending metacognitive processes due to their internal nature, under the premise that you cannot see other people’s thinking. Some teachers expressed that they could not “force” students to think about a specific issue or that it was not possible to verify what students were thinking. Participants also described metacognition as difficult or boring and time-consuming for students. Teachers could not identify the social nature of metacognition or the importance of the social element for generating students’ reflection. They understood metacognition as a process of internalization and often as a task students did (or should do) outside the science classroom on their own. Therefore, a better understanding of the social element of metacognition could provide teachers with ideas to overcome the boredom some students might feel if the instruction is “sit down and think.”

In addition, I found a vast range of metacognitive teaching practices occurring in the science classroom. I created a diagram for the identification of purposes, outcomes, and modes of instruction used in positioning each practice. I also acquired ideas about how to transform instructional strategies into something more student-centered or more oriented toward providing students with tools to become independent learners. The coded classroom observations helped support the idea that teachers increased their use of
metacognitive teaching practices with experience. I also found metacognitive practices were more likely to occur in middle school and non-traditional courses than high school courses.

The exercise of the identification of levels of reflection helped me better understand the ideas provided by participants. Some of them demonstrated misconceptions or a lack of understanding of reflective teaching practices in the science classroom. Others showed an exemplary use of theory and a critical position of their practices and improvement as teachers. It seems that school-wide reflection can help teachers develop more reflective practices and improve their teaching strategies more effectively. However, it is difficult for teachers to transfer the knowledge and practices learned in these school experiences or even in their TEPs when they are not directly connected with science instruction.
CHAPTER 5: DISCUSSION OF STUDY FINDINGS

The purpose of this multi-methods study was to describe the metacognitive knowledge and experiences of beginning science teachers after completing a teacher education program. I used qualitative and quantitative methods to collect data in parallel, analyzed each strand separately, and then triangulated evidence to look for patterns within the data. I also used a subset of classroom observations coded for a larger research study to confirm and have a better understanding of the evidence collected for this research project. In this study, I used the Metacognitive Awareness Inventory for Teachers (MAIT) (Balcikanli, 2011) to generate self-reports about new teachers’ awareness of metacognition. Then I analyzed data collected from open-ended interviews, classroom observations, and artifact analyses to describe teachers’ metacognitive knowledge, instructional practices, and reflective practices as experiences of metacognition.

Discussion

I summarize the main claims of this study in Table 5.1. I dedicate this chapter to presenting evidence in support of seven claims that align with the stated research questions. Because this was an exploratory study, my claims can be considered hypotheses that might be confirmed by further research. I will use the main research questions to frame the discussion of my results and the associated claims.

Research Question #1: What is Beginning Secondary Science Teachers’ Understanding of Metacognition?

To answer the first research question, I used the MAIT survey and completed the results using participants’ interview answers. My Claim #1 is that teachers were aware of
their knowledge of metacognition. However, this knowledge did not increase significantly during their first years of teaching despite accumulating additional metacognitive experiences. This was especially true for teachers’ declarative knowledge of metacognition. The survey-takers \( n=36 \) had an overall score of 3.9 (SD=0.3), which represented 79% of the mean. Mai (2015) in a similar study of elementary science teachers \( n=52 \) found that a score of 80% of the mean (or a 4) could be considered a good perception of metacognition. Since participants’ mean was 3.9, I concluded they had a good perception of metacognition. Their awareness of metacognition could also be affected by their years of experience. However, participants understood metacognition as a complicated and scholarly term that was difficult for students. They also felt it was less necessary or important for them to focus on compared to other elements, such as science content, during their first years of teaching.

Teachers increased their scores in almost all the subscales on this instrument when teaching experience increased, except for declarative knowledge. For instance, the mean of their ability to evaluate instruction increased from 3.7 (SD=1.0) in first-year teachers to 4.1 (SD=0.5) in fifth-year teachers. After four years of experience, teachers could reach a mean slightly above 4 in almost every subscale (e.g., declarative, procedural, and conditional knowledge, monitoring, and evaluation), which indicated a good awareness of metacognition. This was true for all of the subscales expect planning, which had the lowest mean (M=3.7 SD [3.7]). This could indicate that teachers had lower ability levels in planning than in the other metacognitive tasks (monitoring and evaluation). Subscales’ higher mean values were related with more years of experience, which could be associated with a positive effect on teachers’ awareness of metacognition.
In fact, the multiple linear regression showed a positive relationship between those two variables (years of teaching experience and MAIT averages). However, this relationship was not statistically significant. Perhaps with a larger sample it might be possible to find a significant relationship.

Table 5.1

**Alignment of Research Questions, Data Collection, Analysis, and Research Claims**

<table>
<thead>
<tr>
<th>Research questions</th>
<th>Data collected</th>
<th>Analysis</th>
<th>Claims</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. What is beginning secondary science teachers’ understanding of metacognition? Specifically,</td>
<td>MAIT survey interviews</td>
<td>Linear regression and protocol, open and focused coding/themes</td>
<td>1. Teachers were aware of their knowledge of metacognition. However, this knowledge did not increase significantly during their first years of teaching despite accumulating more metacognitive experiences. This was especially true for their declarative knowledge of metacognition. This could be the result of two possible explanations:</td>
</tr>
<tr>
<td>a. To what extent are these teachers aware, or unaware, of their knowledge of metacognition?</td>
<td></td>
<td></td>
<td>a. Years of experience and type of TEP might increase teachers’ awareness of their knowledge of metacognition.</td>
</tr>
<tr>
<td>b. What is participants’ knowledge of metacognition as an element for science teaching?</td>
<td></td>
<td></td>
<td>b. Participants understood metacognition as a complicated and scholarly term, difficult for students, and as not as necessary or important to focus on during their first years as other elements, such as science content.</td>
</tr>
</tbody>
</table>

2. Teachers understood a connection between metacognition and thinking as scientists. However, they frequently did not have a clear idea of how to apply metacognition when they used scientific practices or to relate it with the epistemology of science. This might be because they did not have enough knowledge of metacognitive teaching practices.

3. Participants’ most common understanding of metacognition was as self-evaluation. They did not often relate it with planning or monitoring. Moreover, they did not connect metacognition with the social aspect of this construct.
2. What are the common instructional practices of metacognition (i.e., metacognitive teaching) in beginning science teachers?

   a. What elements do teachers believe affect their instructional practices of metacognition (or metacognitive teaching) as part of science instruction?

3. What are beginning science teachers’ reflective practices as experiences of metacognition?

   a. What factors affect beginning science teachers’ reflective practices?

4. What knowledge and experiences of metacognition affect teachers’ instructional practices of metacognition (or metacognitive teaching)?

   a. Elements affecting those experiences might include the context where they took place, level of teaching experience, and teachers’ beliefs about metacognition, teaching and learning.

5. Teachers who frequently used metacognitive practices in their science lessons recognized the importance of practice and writing prompts to help students develop metacognitive skills. This was likely to have occurred because these teachers had flexibility to make curricular decisions, received PD, or were part of school-wide reflective practices.

6. Reflective practices, as experiences of metacognition, can help beginning science teachers become more effective. However, critically reflective teachers did not necessarily use more reflective teaching practices.

   a. What factors affect beginning science teachers’ reflective practices?

4. In accordance with their knowledge of metacognition, teachers often used metacognition for individual learning accountability and formative assessments.

   a. What elements do teachers believe affect their instructional practices of metacognition (or metacognitive teaching) as part of science instruction?

Almost all of the subscales increased their value as participants’ years of experience increased, except for the declarative knowledge subscale. Its mean remained steady (i.e., no changes between year 0 and year 4) (M= 4.1). In other words, experiences of metacognition during participants’ first five years of teaching did not help them increase what they knew or believed about metacognition.

The lowest score was item #21 (“I know when each teaching technique I use will be most effective”), the only item with a mode = 3. This item was related to conditional
knowledge, which refers to how and when to use a teaching strategy and requires experience. As a result, I was expecting a lower score in items related with conditional knowledge than in declarative or procedural knowledge. On the other hand, these teachers had higher scores in items #22 (“I try to use teaching techniques that worked in the past”) (procedural knowledge) (M=4.3 [SD=0.5]), and #18 (“After teaching a point, I ask myself if I’d teach it more effectively next time”) (evaluation) (M=4.3 [SD=0.6]). Teachers seemed to need and value teaching experience in order to use what worked for them in the classroom and strive for improvement.

Finally, another variable that might have positively affected teachers’ metacognitive awareness was the type of teacher education program they experienced. Despite the lack of statistical significance, the type of teacher education program had the second highest value as a predictor of metacognitive knowledge. Teachers in the study who graduated from the MAT program had higher MAIT scores than teachers who graduated from the UG program. Mai (2015) found the interaction between level of TEP and age in elementary science teachers to be significant. It seemed that older teachers who completed a Master’s program might have more metacognitive awareness than younger teachers who earned a teaching endorsement in an undergraduate teacher education program. Therefore, I concluded that years of experience and type of TEP might increase teachers’ awareness of knowledge of metacognition. However, a larger sample size is needed to find a statistically significant correlation.

Relationship to other researchers’ findings. Other researchers have found high metacognitive awareness in beginning teachers using similar instruments (Mai, 2005; Memnum, 2013; Roehring, Turner, Grove, Schneider, & Liu, 2009). There is a general
agreement that metacognitive awareness is important for teachers during their first years (Seraphin & Philippoff, 2012; Memnun, 2013; Roehrig et al., 2009). For example, Memnun (2013) concluded that metacognitive awareness might help teachers become more strategic, increase their problem-solving skills, and improve their learning process during these early years. Furthermore, Roehrig et al. (2009) affirmed that greater metacognitive awareness could help beginning teachers improve their practice and become more effective, reducing the gap between their beliefs and what they do inside the classroom.

The positive relationship found between experience and metacognitive awareness in this research project concurs with other studies. This relationship could have an effect on teachers’ beliefs, instructional practices, and self-efficacy. Roehrig et al. (2009) concluded after their study that experience and metacognitive awareness helped teachers reduce the mismatch between their beliefs and instructional practices. Seraphin and Philippoff (2012) found that teachers who were more aware of their metacognition could become better teachers with time and experience. Additionally, Hébert (2015) explained that teacher reflection, which could be related with awareness of metacognition, takes time to develop like any other skill.

**Metacognition: a scholarly and complicated term.** After the survey, I used interviews and classroom observations to gain a better understanding of what participants knew about metacognition. Based on our conversations, I concluded that despite their high awareness of metacognition, participants understood metacognition as a complicated and scholarly term, difficult for students, and not as necessary or important to focus on during their first years as other elements, such as science content.
Almost all the participants I interviewed for the qualitative strand of this study could identify the traditional definition of metacognition, “thinking about thinking.” Based on word count, the most common definition they used for metacognition was “thinking how to think or reflect about learning.” Participants noted metacognition had an important role in learning. However, they identified the term “self-regulation” as related more with independent learners than with metacognition. Participants identified metacognition with reflection, thinking as scientists, self-evaluation, and making connections.

Frequently, participants could identify the definition of metacognition but had misconceptions about it or were unsure what “thinking about thinking” meant. Most of them considered it a complicated term and did not encounter it after their TEP. Some participants used words like “education-y” or “intimidating” to describe metacognition. Moreover, after identifying the definition as “thinking about thinking,” some participants explained metacognition as a double cycle of thinking or “getting further.” However, some used a literal understanding of “thinking about thinking,” explaining metacognition as evaluating and then reevaluating a conclusion or developing a hypothesis and then retracing how they generated it.

Furthermore, participants demonstrated prejudices about metacognition. For instance, almost all of the teachers I interviewed described metacognition as a complicated term and considered it difficult for students, with or without evidence. They also mentioned needing more teaching experience to use metacognitive teaching practices or needing to focus on content during their first years, as they felt those practices would come later.
Participants often described students’ difficulties with metacognitive strategies for learning. Teachers who used these strategies characterized students as unused to “thinking outside the box” or as having been “ultra-regulated.” As a result, according to participants, students did not want to spend time reflecting about their learning. Teachers noted that students considered reflection and metacognition in the science classroom “annoying,” “uncomfortable,” “useless,” “boring,” or “hard.” Participants also said students “didn’t like” these practices, “didn’t see the point of it,” “didn’t care,” “didn’t want to think,” “were not ready,” “not used to it,” “got tired,” “wanted the ‘right’ answer,” and “didn’t make ‘obvious connections.’” Teachers often mentioned they preferred to use the word “reflection,” especially during instruction, because it was more common and easier for students.

Moreover, participants did not encounter references to metacognitive teaching in their schools, and some commented that more experienced teachers at their schools rejected these ideas. Whether this phenomenon was perceived or real, it could explain why participants put metacognitive teaching on hold, even though they might have strong beliefs about its role in students’ learning. Allen (2009) followed up with novice teachers after an innovative and progressive teacher education program in Australia, concluding that alumni were unable or unprepared to use key features of the program during their practice if they were not supported by their new school communities. As Allen found, “Novitiates struggle to provide change agency within the school environment unless the community within which they work supports their attempts; if not, they succumb to traditional socialization processes” (Allen, 2009, p. 653). Thus, it is difficult for new teachers to use metacognitive teaching in their classrooms if they perceive an emphasis
on content or a disdain for these more student-centered strategies for learning in their schools.

**Relationship to other researchers’ findings.** Wilson and Conyers (2013) described metacognition as a “double layer” of thinking. As they explained it, metacognition could represent a double layer when a learner thinks or selects a strategy for problem-solving, or could be helpful to evaluate the features or limitations of a model, but not to re-evaluate an evaluation. Participants had some notions about metacognition as “going further” or a “deeper reflection.” They understood the concept of a double cycle of thinking, but some of them had difficulties explaining how to use it in the science classroom. Perhaps that is one reason why they preferred to use the term reflection instead of metacognition.

Several authors have explained that reflection is often used to describe metacognition, especially in educational settings, as an instructional practice in the classroom, or to understand science (Azevedo, 2005; Bixler, 2011; Silver, 2013; White & Frederiksen, 1998; Wilson & Bai, 2010; Zohar & Barzilai, 2013). It seems that science teachers see “reflection” as a simpler term than metacognition’s “double cycle” of thinking. In other words, this could serve as evidence that participants considered metacognition a more complex term.

Moreover, researchers have explained that many teachers lack a rich understanding of metacognition and how it functions. Even those familiar with the concept have not necessarily developed methods for integrating it into their curriculum (Veenman et al., 2006). In other words, teachers may have difficulties explaining or using metacognitive teaching practices, even when they have a good understanding of what the
term might mean. This is also true for scientific and engineering practices and metacognition. Participants knew the definition of metacognition and understood there was a connection between this construct and science and engineering practices. However, they often did not know how to use metacognition or had misconceptions about it.

Metacognition and students’ development. I agree that metacognition could be a difficult skill for learners, as participants described. Metacognition is considered a higher-order thinking skill and part of the process of conceptual change (Amin et al., 2014; Lemons et al., 2013; Wilson & Conyers, 2013). Therefore, it should require effort from learners and teachers. It is a common conception that metacognition is better suited for older students because teenagers are better at abstract thinking skills, based on Piaget’s ideas. However, Amin et al. (2014) suggested that it is a mistake to attribute logical and conceptual changes to learners’ maturation. They found that there is enough evidence to support the claim that even preschoolers can show reasoning abilities. These authors explained that often teenagers are better at logical skills because they have more knowledge and experience in contact with the experiential world and more things to say than younger students.

Participants expressed the sense that students did not like metacognition, did not want to think, or found it annoying or uncomfortable. Burke and Dunn (2006) explained that reflexive pedagogies raise uncertainties for learners. In other words, metacognition faces students with the challenge of the unknown, because its focus is not on the final product but on the process and the strategies chosen to solve a problem. Burke and Dunn (2006) argued it is always risky to encourage students to take a reflective approach because they might challenge dominant regimes. Students developing critical thinking
might question the status quo of situations around them, which could be difficult for teachers to handle, especially during their first years. It might be easier to focus on science content than to encourage students to question scientific theories or procedures. However, critical thinking is a desired outcome in a science classroom and a skill required for citizens of the 21st century to enhance innovation, problem-solving, creativity, and collaboration. Therefore, new teachers must develop the ability to accede some of their control over students and empower them to become responsible for their own learning.

Additionally, I agree students may feel uncomfortable using metacognition. After following high school chemistry students for two years, Thomas and McRobbie (2013) found that participants felt stressed when they used metacognitive strategies during inquiry lessons. However, metacognition is nevertheless a skill students need for empowerment and becoming independent learners (Holton & Clarke, 2006; Wilson & Conyers 2013; Zimmerman, 2002). To help students, Thomas and McRobbie (2013) recommended establishing classroom rules, routines, and an appropriate learning environment to develop metacognitive skills. I will elaborate more on the context of metacognitive experiences later in this section.

Participants in this study who frequently used metacognition (e.g., Lucy, Mary, and Frank) agreed that students were not used to reflecting and needed practice. Coffey et al. (2011) explained that students try to find the “correct answer” when content is the subject matter knowledge of a course. In other words, if the evaluation of the course is based on content, theories, and right or wrong answers, students will try to accommodate to those expectations. Therefore, metacognitive practices might seem annoying or
pointless to them. Furthermore, if students are used to a more traditional, lecture-based style of teaching, asking them to use metacognition might be unfamiliar and uncomfortable at first.

Posholm (2011) concluded that teaching metacognitive strategies requires time and intention but is worth the effort. Howitt and Wilson (2014) found that students felt more confident in making their own judgments and developed more sophisticated views of science when teachers gave them opportunities to reflect about their learning after an inquiry activity. Therefore, metacognition can help learners develop confidence in their ideas by helping them understand how they generate those ideas (i.e., epistemic metacognition). Metacognition can thus help learners acquire a sophisticated and useful understanding of science. As some participants explained, preparing the context and environment for metacognitive teaching and giving students opportunities to practice ahead of time can also help teachers facilitate more reflection in their science classes.

In sum, the concern that metacognition might be difficult for students to use in the science classroom is legitimate. Additionally, participants expressed that they needed more teaching experience to use metacognition or felt they needed to focus on mastering the content during their first years as teachers. They often recognized they were not using metacognitive teaching in their classes. However, participants using metacognitive practices often began doing so in their first year as teachers. Thus, when teachers know how to apply metacognitive teaching practices, experience can help enhance their strategies, but it is not required for teaching metacognition.

**Metacognition and thinking as a scientist.** Participants struggled with knowing how to enact metacognition using scientific practices. They often perceived a connection
between teaching science and metacognition, but they did not know exactly how to implement this connection in the classroom. Therefore, Claim #2 in this study is:

*Teachers understood a connection between metacognition and thinking as scientists.*

*However, they frequently did not have a clear idea of how to apply this connection when using scientific practices or how to relate it with the epistemology of science. This may be because they did not have enough knowledge of metacognitive teaching practices.*

Participants identified the development of higher-order thinking skills while using scientific practices as “thinking as scientists.” However, they did not have a clear understanding of epistemic metacognition or the nature of science. Only two participants mentioned a concrete idea about epistemic metacognition as recognizing bias and the error of measurement when they conducted an experiment. Some participants mentioned that metacognition was related with making connections about how they came up with an answer or their reasoning behind it. Osborne (2014) explained that epistemic metacognition was related with answering questions such as how and why. However, participants did not relate these connections with scientific practices, but rather with prior knowledge or explaining reasons for their instructional decisions. Moreover, they recognized that they did not often use the nature of science in their classroom.

**Relationship to other researchers’ findings.** These observations are consistent with researchers who have concluded that science teachers often lack knowledge of metacognition. For instance, Veenman et al. (2006) affirmed after a review of research studies in science education that “many teachers lack sufficient knowledge about metacognition” (p. 10). Ben-David and Orion (2012) concluded that after several years of
experience and professional development, elementary science teachers knew little about metacognition and expressed prejudices toward it.

Metacognition should be an important element in teachers’ use of science and engineering practices. Schraw et al. (2006) explained that teachers need to facilitate learning through reflective thinking and metacognition when they use inquiry. Metacognition has an active role in students’ ability to construct and test hypotheses and interpret findings. It is also related with how science generates learning (i.e., the epistemology of science) and how and why knowledge is considered valid and true.

Nevertheless, metacognition is not often used in the science classroom. Researchers have found evidence that science teachers believe students will understand scientific practices by using them. In other words, there is no need to reflect about scientific practices because students will develop an understanding of them implicitly (Bartos & Lederman, 2014). For example, students will be able to understand and apply scientific practices in their lives because they performed lab practices during their science lessons.

Science teachers might use guided inquiry, such as cookbook labs, to teach science with the belief or hope that students will make the transference by themselves and use these skills in the future. Burgin and Sadler (2015) concluded that students require explicit approaches to teaching and learning the NOS when they use science and engineering practices. Teaching with intention and having clear goals for developing a deep understanding of when, how, and why to use scientific practices is a fundamental element of developing students’ long-term scientific skills.

**Metacognition and content matter.** Teaching experience seemed to have an influence on teaching metacognition. When revisiting observations from the larger study,
I noticed that 12% of first-year secondary science teachers’ lessons demonstrated reflective practices versus 42% of fifth-year teachers. Moreover, 16% of biology and chemistry lessons included reflective practices, compared with 44% of lessons from elective courses (e.g., principles of engineering, zoology, etc.). Accordingly, teachers commented that in their first years they focused on teaching the content. This was especially true in traditional high school science courses, such as chemistry, biology, or physics.

This concurs with Spurce and Bol’s (2014) research. Teachers who participated in their study commented that they had limited time and space in the curriculum for teaching learning process skills (such as metacognition, reflection, or the nature of science) because content-specific demands were high. Additionally, Bartos and Lederman (2014) found that secondary science teachers perceived NOS and scientific practices as inferior to traditional subject matter. Even when secondary science teachers demonstrated strong content knowledge, they accorded more importance to teaching theories than to promoting scientific practices and the nature of science (Bartos & Lederman, 2014). Thus, science teachers often focus their attention on covering content rather than on developing scientific skills or reflections about the NOS.

Further, Bartholomew, Osborne, and Ratcliffe (2004), who studied the nature of science in secondary teaching, concluded that what influences teachers’ instructional decisions is not their subject matter knowledge but their conception and understanding of their learning goals. In other words, what teachers perceive they need to teach or will be assessed over is what will guide their curriculum and instruction. Bartholomew et al. (2004) explained that if teachers perceive a strong focus on content, there will be tension
between finding time to teach the nature of science (as part of epistemic metacognition) and what they need to cover. The authors concluded that generally science teachers give little space to meta-level reflection and answer questions about what we know instead of how we know it (i.e., epistemic metacognition). Moreover, teachers focused their attention on what would have a greater impact on students’ test performance (Bartholomew et al., 2004). Overall, if external evaluation is based on content, teachers will focus their attention on this content and will rarely use metacognitive teaching.

**Metacognition and self-evaluation.** Claim #3 of this study is: *Participants’ most common understanding of metacognition was as self-evaluation. They did not often relate metacognition with planning or monitoring and did not consider the construct’s social aspect.* Participants often identified metacognition with self-evaluation and had a good understanding of the connection between assessing performance and reflection and metacognition. Almost all of them mentioned that they used metacognition as an assessment for what went well or what they learned at the end of a lesson. Schraw (1989) identified three essential skills for metacognition: planning, monitoring, and evaluation. Planning is done before an activity and involves setting up goals, selecting a strategy, making predictions, or allocating time. Monitoring occurs during the task or activity and involves self-testing of how the task is going. Evaluating is a post-task activity and refers to the assessment of outcomes and performance based on initial goals and strategies (Balcikanli, 2011; Schraw, 1998; Silver, 2013). Evaluation is thus an important component of metacognition, although not the only one. Planning and monitoring are also important for developing an awareness of learning.
Frequently, participants described metacognition as self-reflection, looking back on what happened after a lesson or an event. However, they understood thinking about thinking as an individual activity of internalization. Often teachers described metacognition as “sitting down and thinking,” since thinking and reasoning are internal operations related with thought. They did not mention metacognition as part of a process of socialization or collaboration. Dewey (1910) explained thought as “everything that comes to mind, that ‘goes through our heads’” (p. 1). In this conception, thinking is something that occurs inside our minds and is not possible to see directly (i.e., with our senses). However, Heritage (2014) explained Vygosky’s ideas about learning as an intra- and interpersonal construct. Learning starts internally (intrapersonal) but is enhanced when the learner interrelates with others (interpersonal).

**Relationship to other researchers’ findings.** Metacognition has often been related with a process of self-reflection, introspection, or internalization (Papleontiou-louca, 2003). Heritage (2013) explained that “metacognitive activity is generally considered to take the form of an internal dialogue that enables self-monitoring during an activity” (p. 102). However, true metacognition moves beyond the internal realm. Metacognition derives from learning theories based on socio-constructivism, in which learning is socially mediated. Thus, while thinking occurs inside our minds, metacognitive skills will be enhanced through collaboration.

There is a consensus among researchers on the social and cultural aspects of metacognition and how it is embedded in social interaction and enhanced using social practices (Edwards & Thomas, 2010; Thomas & McRobbie, 2013; Thompson & Pascal, 2012; Papleontiou-louca, 2003; Porayska-Pomsta, 2016). Several studies affirm the
importance of peer interactions, collaborative situations, small group discussions, and social interactions to promote metacognition and reflective practices for teachers and students (e.g., Adler et al., 2015; Azevedo, 2005; Bixler, 2011; Frith, 2012; Kramarski et al., 2002; Postholm, 2011; Siegel, 2012). However, the disconnect between research and what is happening in the classroom is not new. Thompson and Pascal (2012) advocate promoting time and space for reflection and metacognition among learners, not only because this promotes critical thinking, but also because it takes into account the cultural and structural factors that shape professional and social practices. These are skills students will need to become successful in school and in their future lives. However, this will only occur when we can reduce the gap between what we know about learning and what happens in the science classroom.

Research Question #2: What are Common Instructional Practices of Metacognition (Metacognitive Teaching) in Beginning Science Teachers?

Claim #4 for this study is as follows: in accordance with their knowledge of metacognition, secondary science teachers often understood and used metacognition for individual learning accountability and formative assessment. Participants in this study generally understood metacognition as related with self-evaluation. Accordingly, they described using metacognitive teaching practices for formative assessment, such as exit tickets, learning summaries, opening questions about the prior lesson, or reflections before or after a quiz. They usually understood metacognition as a self-reflection or self-evaluation of what students knew or what when wrong during an experiment.

Based on Flavell’s (1979) model, knowledge of metacognition informs experiences of metacognition through actions and goals, and vice versa. Therefore,
experience should increase knowledge of metacognition and knowledge of metacognition is needed to generate an experience. As previously described, participants often understood metacognition as self-evaluation, so their practices were related with formative assessment. On the other hand, they understood a connection with scientific practices, but often did not know how to apply or use metacognition in inquiry lessons. Therefore, they frequently reported a low use of metacognitive strategies. This was confirmed after the analysis of 287 classroom observations of beginning science teachers, in which 16% to 23% of the lessons from teachers with one to four years of experience used reflective practice. I observed that the percentage of lessons with reflective practices grew slightly during teachers’ early years, so their knowledge of metacognition might be informing their experiences and practices, and vice versa. However, this growth is still small, and work is still needed to support beginning teachers in their use of metacognitive strategies.

**Relationship to other researchers’ findings.** Researchers have reported that knowledge and experiences of metacognition have an effect on teachers’ metacognitive teaching practices (Wilson & Bai, 2010; Roehrig et al., 2009; Zohar & Barzilai, 2013). Wilson and Bai (2010) explained that individual teachers’ understanding of metacognition was related to the “instructional strategies they perceived to be effective in helping students to become metacognitive” (p. 285). Therefore, participants might understand metacognition as self-evaluation because they saw it as beneficial for students’ learning and for informing their teaching through formative assessment practice.
Participants recognized they did not often use metacognition, a finding supported by classroom observations. This concurs with similar studies, such as Spruce and Bol’s (2014), which concluded that teachers’ knowledge and class applications of self-regulated learning were generally low.

**Metacognition and assessment.** I agree that metacognition has a fundamental role in formative assessment (interactive and planned) to support science teaching and promote conceptual understanding. However, if it is a skill teachers want to develop with intention in their students, which requires time to practice and effort to develop, it is also important to consider as part of summative assessment. In fact, some participants held misconceptions about the impossibility of knowing what students are thinking (e.g., David) or not being able to use reflections as part of their summative assessment because opinions could not be graded (e.g., Paula). Bartos and Lederman (2014), in a study about how secondary science teachers used the NOS and scientific practices, concluded that participants gave more importance to subject content by using summative assessments as an indicator of this importance. In other words, teachers focus their summative assessment on what they consider important or part of their curriculum, an insight I will discuss in more detail later in this section.

**Writing prompts and practice.** Claim #5 is that *teachers who frequently used metacognitive teaching in their science lessons recognized the importance of practice and writing prompts to help students develop metacognitive skills.* Metacognition, as with any other skill, requires practice. Teachers using it in their classroom recognized this element as important to effectiveness. Moreover, because metacognition is also related
with thinking skills, teachers recommended writing prompts to follow up on and provide feedback about students’ reflections and thinking.

**Relationship to other researchers’ findings.** Heritage (2013) explained that new learning requires teachers to generate and gather evidence about learning with intention. Teachers need to plan and design the evidence (i.e., learning outcomes) they will ask for from their students. If teachers need practice to develop metacognitive skills, this is also true for students (Bell & Cowie, 2001; Lovett, 2013; Silver, 2013; Wilson & Conyers, 2013). Moreover, researchers agree on the importance of giving students intentional metacognitive writing prompts to demonstrate their learning when using science and engineering practices and the NOS (Adler et al., 2015; Bixler, 2011; Peters & Kitsantas, 2010; Trauth-Nare & Buck, 2011). Writing prompts can help students develop conceptual understanding and metacognition. This also confirms my recommendation for formal outcomes to help teachers develop more sophisticated metacognitive teaching practices.

As discussed previously, metacognition can be difficult for teachers and students and requires time and practice. Silver (2013) explained that teaching metacognition can be time consuming. Lovett (2013) added that metacognition requires practice through an investment of time in order to provide feedback on development. However, it is unsurprising that neither teachers nor students would be willing to use instructional time and efforts to develop a skill that is not part of the course achievement goals.

Teachers also need certain conditions to promote the use of metacognitive teaching practices in their classrooms. Participants in this study suggested that they needed *flexibility to make curricular decisions, professional development, and school-*
wide reflection to effectively include metacognitive teaching practices in their curriculum.

**Flexibility and control over instructional decisions.** Participants who used metacognition recognized that they had control over the decisions inside their classrooms, which helped them implement new strategies and metacognitive teaching practices. On the other hand, teachers who had regulated curricula or were teaching courses for the first time felt that they could not include reflective practices because they needed to follow what other teachers were doing or had to teach the same content at the same pace.

**Relationship to other researchers’ findings.** Researchers have found that flexibility is an important support for reflective practices (Moallem, 1997; Porayska-Pomsta, 2016). Metacognition requires time to develop, and teachers need flexibility to adapt their courses to students’ needs. Not all students learn in the same way or at the same pace (Wilson & Conyers, 2013). Using metacognitive teaching practices and formative assessment can help teachers apply strategies to differentiate students’ learning, provide the support they need, and help them understand how they learn (Heritage, 2014; Wilson & Conyers, 2013). Therefore, it is fundamental that teachers have control over their instructional decisions.

**Professional development for beginning teachers.** Participants described metacognition as a scholarly term and often did not have contact with it after their TEPs. Therefore, professional development during these early years could help reinforce what teachers learned about metacognition as student teachers. This PD could also help new teachers implement metacognitive learning strategies using the knowledge and wisdom gained after their experiences in the real world during those first years. In this study,
science teachers participating in professional development had a better understanding of metacognition. Professional development can thus help teachers transfer their knowledge and practices of metacognition into their teaching.

**Relationship to other researchers’ findings.** Parker and Heywood (2013) concluded that training in metacognition helped elementary school teachers develop knowledge of their own learning when they faced a problem, relate this information with their elementary curriculum, and formulate pedagogical insights about their teaching. Nevertheless, they did not present evidence for how these pedagogical insights could be transferred into metacognitive teaching practices. Moreover, Veenman et al. (2006) suggested that prolonged training guarantees the smooth and maintained application of metacognitive activity. In other words, practice will enhance the use and transfer of metacognition. Teachers should practice and be aware of metacognition so that they will consider it an important skill to develop in their students.

**School-wide reflection.** Some teachers commented during interviews that participating in school-wide professional development and reflective practices helped them develop awareness of the importance of metacognition (e.g., Henry, Jean, Pam). York-Barr et al. (2006) supported involvement in whole-school learning and reflection as an effective way to enhance innovation and change. School-wide professional development can create a supportive environment that enhances collaboration among peers and support from school leadership. Teachers may also develop a sense of urgency or importance when the entire school is involved in setting goals. If this were combined with flexibility in decision-making, time, and practice, teachers could become successful at adopting effective teaching practices based on teaching and learning theories.
Finally, during analysis I devised a diagram to describe participants’ teaching practices based on their purpose, mode, and outcome. I realize this diagram could be enriched and improved with the analysis of more teaching practices, but it provides a starting point for promoting awareness of the variety of instructional practices and purposes that can be used in the science classroom. This diagram could also be helpful for TEPs to explain practices of metacognition in the classroom and provide examples for how it can be applied in practical situations.

**Research Question #3: What are Beginning Science Teachers’ Reflective Practices as Experiences of Metacognition?**

I analyzed participants’ interviews to identify their level of reflection based on Cartwright’s (2011) classification of reflective awareness (as an indicator of effective experience of metacognition). I agree that any level of reflection can help teachers improve their practice (Cartwright, 2011). I further agree that no difference exists between “good” or “bad” reflection (Collin et al., 2013). The effectiveness of reflection depends on multiple factors, such as the purpose, teachers’ goals, etc.

After my analysis, Claim #6 holds that *reflective practices, as experiences of metacognition, can help beginning science teachers to become effective. However, critical reflective teachers did not necessarily used more reflective teaching practices.* Analyzing the level of the participants’ reflection based on Cartwright (2013), I found that I coded segments using the three levels of reflection for almost all participants. Larrivee (2008b), who developed similar levels of reflection to Cartwright (2013), explained that a reflective practitioner incorporates all levels of reflection. Therefore, it is common to find all levels when a teacher reflects about a teaching event. However,
McGregor (2011) found that deepening the level of reflection can make it more meaningful and support teaching improvement and creativity more effectively than lower levels of reflection.

**Reflective awareness.** Reflection in teacher education has been a target of many discussions and studies (Collin et al., 2013). In general, it is considered a necessary practice for new teachers and a tool for learning to teach (McGregor, 2011). Teachers go through a process of learning during the early years of their career. Ideally, they come from teacher education programs that provide them with theories and instructional strategies for how to teach science effectively. For example, participants’ science TEPs promoted socio-constructivist approaches to teaching and learning, the 5E model of instruction, the NGSS, and using technology in the classroom. During their first years of teaching, teachers need to adapt all the knowledge, experiences and beliefs they acquired during their TEPs and use them in the context of their new school environment. Therefore, reflective practices can help them during their first years as teachers to adapt their knowledge to students’ needs. Having an understanding of levels of reflective awareness can help teachers deepen their reflection. However, I could not find a direct relationship between reflective awareness and the use of metacognitive teaching practices in the science classroom.

There is a general agreement that reflective practices can improve teaching and learning in the classroom (Belvis et al., 2013; Roehrig et al., 2009). Nonetheless, teachers using conscious critical reflection (CCR) were not necessarily those using more metacognitive teaching practices. In general, teachers using CCR had a better understanding of applying metacognitive teaching and understood metacognition was
necessary to teach scientific practices. They also had a more student-centered approach to teaching, as in the case of Lucy and Matt. Emma and Jean also used CCR during our interview. However, they had some misconceptions about how to use metacognition in the classroom. Furthermore, while Mary’s interview had more segments coded as UR, she was using exemplary metacognitive teaching practices.

Henry’s case was also interesting for analyzing the relationship between reflective practices and knowledge of metacognition. He was teaching at a small school, had flexibility and control over his decisions, was open to learning experiences, and was participating and facilitating a school-wide PD. I expected he would have a high level of reflective practices (i.e., conscious critical reflection, CCR). However, based on his number of coded interview segments, his level of reflection was unconscious (UR). I concluded that this might be because he did not have enough knowledge about more complex metacognitive teaching practices. Therefore, his reflections were focused on teaching as “transferring knowledge” and direct instruction. In other words, Henry’s metacognitive experience, reflecting about his metacognitive teaching practices, might be influenced by a lack of metacognitive knowledge about how to enact complex teaching practices in the science classroom. Knowledge and experiences of metacognition are clearly important, although there may be other elements that affect the enactment of metacognitive teaching practices.

**Relationship to other researchers’ findings.** Reflection is multidimensional in nature (Korthagen & Vasalos, 2005). Therefore, distinguishing between levels can help promote teachers’ growth and improvement of reflective skills (Cartwrite, 2011;
Korthagen & Vasalos, 2005; Larrive, 2008a). Memnun (2013) also found that metacognitive awareness supported learning.

Other researchers have reported a mismatch between what teachers know they should be doing (e.g., using metacognition when they use scientific practices) and what they are actually doing (e.g., not using metacognitive teaching during their first years as teachers). Researchers concluded that this disconnect could be related to a lack of knowledge or lack of self-awareness (Roehrig et al., 2009).

Haug and Ødegaard (2015) agreed that teachers require pedagogical content knowledge (i.e., the interaction between content and pedagogical knowledge) to use complex strategies to understand students’ thinking. Therefore, I believe Henry’s experiences of metacognition as part of PD at his district could help him develop awareness of his pedagogical decisions and support the transfer of these experiences into metacognitive teaching practices.

**Other elements that might affect reflective awareness.** Teachers cannot apply metacognitive experiences without first knowing how to do so. Reflective practices can help teachers effectively use strategies to accomplish their goals. However, there are elements that might affect reflective practices as experiences of metacognition. *Some elements that may affect teachers’ reflective practices as experiences of metacognition include teaching experience, context, and beliefs about metacognition, teaching and learning.*

*Experience and reflection.* One of the elements that may have affected metacognitive practices was teaching experience. Teachers used their past experiences to inform their teaching and make instructional decisions. For example, Betty, a fifth-year
teacher, made comments about her chemistry classroom that aligned with the UR level of reflection. In the case of Paula, the first-year teacher, her reflection during the interview was dominated by UR segments. Cartwright (2011) explained that teachers learn from their own and others’ experiences. Therefore, reflection upon teaching is crucial for teachers (Jove, 2011). Reflection on past experiences and learning strategies can develop teachers’ self-efficacy and understanding of themselves as learners (Mycroft & Gurton, 2011). Therefore, experiences can help teachers develop deeper reflection about their strategies. Conversely, a lack of experience might promote superficial reflections that do not lead to improvement. This also concurs with results found in the MAIT survey and classroom observations about the relationship between experience and metacognitive awareness and teaching practices.

**Context and reflection.** The other element that could affect teachers’ reflective practices was the context in which the reflection occurred. Malthouse et al. (2014) defined context as the physical surroundings, social setting, and individual dispositions contributing to the quality of reflection. For example, in Mary’s case, answering interview questions in the car might have affected her level of reflection. Busy teachers might also tend toward more superficial reflections than those who have more time to stop and think about the past. Consider Pam, for example, who was teaching several new courses. Despite her exemplary process of school-wide reflection and professional development, her reflection was not dominated by CCR segments.

Researchers have also supported the importance of the context in which reflection takes place. Edwards and Thomas (2010) insisted that educators should be concerned with developing supportive contexts to enhance reflection as part of social conduct. They
argued that the context in which teachers solve problems will have a significant impact in their decisions. Collin et al. (2013) agreed that context might influence teachers’ ability to reflect. Supportive school environments can provide opportunities to reflect that will enhance teachers’ reflective abilities and metacognition. Larrivee (2008a) explained that “even novice teachers can deepen their level of reflection with powerful facilitation and mediation within an emotionally supportive learning climate” (p. 346). Therefore, Parker and Heywood (2013) urged TEPs to promote reflective environments to prepare teachers to become more metacognitive in their professional careers.

Context is also important for learners, so teachers should promote a learning environment that supports students’ reflection and metacognitive experiences. Although teachers in this study said that students found metacognitive practices difficult, working in a supportive environment and creating specific interaction rules can help students become more reflective. Trauth-Nare and Buck (2011) explained that formative assessment requires a classroom culture that encourages reflection and interaction. Researchers have also found that teachers need to develop a non-stressful and stable classroom learning environment to enhance students’ metacognition (Azevedo, 2005; Thomas & Anderson, 2010; Thomas & McRobbie, 2013). Moreover, a learning environment that supports metacognition can become a virtuous cycle of reflection. An adequate environment can help students’ metacognition, while reflective metacognition can generate a rich learning environment by promoting self-awareness and improvement (White et al., 2009). Teachers need to prepare the environment and promote certain rules and social contracts to support students’ reflection and metacognition.
To build this supportive environment, teachers can draw on clues from the NOS and the epistemology of science. For example, some of the NOS features that Osborne (2014) identified could help build social contracts to enhance metacognition. These include, for example, the ideas that science is empirically based; scientific knowledge is imaginative and creative; and science is subject to change, socially negotiated, and culturally embedded. Science teachers could transfer these features into their classroom so that students might experience epistemic metacognition and learn how to use it in real situations.

**Beliefs and reflection.** The last element that might have an influence on the quality of reflection and metacognitive experiences is beliefs about teaching and learning. Korthagen and Vasalos (2005) explained in their onion model that inner levels affect outer levels. Therefore, beliefs will affect teaching competencies and behaviors. For example, although David had a strong knowledge and passion for the NOS, he felt high school students were not ready to understand it and thus was not using it in the classroom. David’s beliefs could also be impacting his level of reflection.

Other researchers have found the impact of beliefs on science teachers. Teachers who believe metacognition is difficult for students do not often include metacognitive experience in their classrooms. Beliefs also affect teachers’ level of reflection and their own experiences of metacognition. For instance, teachers with traditional views about science teaching were more likely to use UR, based on Cartwright’s (2011) levels of conscious reflection. After studying self-regulation, Spruce and Bol (2014) concluded that teachers’ beliefs about their students’ capability for self-regulation may limit their willingness to incorporate opportunities to initiate activities. Maggioni and Parkinson
(2008) explained that “teachers’ beliefs about how students learn, as well as teachers’ own epistemic beliefs about knowledge, influence the types of instructional practices that they use in classrooms” (p. 109). Powell (1996) also recognized teachers’ personal and epistemic beliefs as elements affecting classroom decisions and instructional style. Corsi (2010) concluded after studying SRL that teachers still do not use student-centered methods because there is still the belief that direct instruction allows the teacher to maintain control and promotes positive learning outcomes.

On the other hand, Herman et al. (2015) explained that teachers who implemented NOS strategies were deeper reflectors. These teachers could relate practice to knowledge about how people learn, used their experience and examples of their own practice, and looked for improvement (Herman et al., 2015). This description aligns with what Cartwright (2011) called conscious critical reflection (CCR) and with comments of participants classified as CCR.

Therefore, in order to enhance metacognitive experiences, it is important to prepare an adequate environment and pay attention to the context in which reflections are going to occur. The epistemology of science can provide clues to teachers about what sort of environment science requires to generate new knowledge. Therefore, epistemic beliefs about learning and knowing have an influence on the instructional decisions of science teachers. Additionally, the context in which experiences of metacognition take place may affect the quality of reflections.
Research Question #4: What Knowledge and Experiences of Metacognition Affect Teachers’ Instructional Practices of Metacognition (or Metacognitive Teaching)?

The last and final claim of this study is that science teachers’ knowledge and practices of metacognition might not transfer into metacognitive teaching practices if those teachers do not have an experience of metacognition embedded in science content.

After the interviews, I visited Mary and Frank’s classes because they described metacognitive teaching practices as part of their regular science instruction. Mary was a fifth-year teacher of 6th grade science who used individual learning summaries and reflective questions at the end of her lectures. These summaries and reflective questions were part of students’ science journals, which Mary graded every quarter. She explained she learned this teaching strategy after taking an undergraduate geology course.

Frank, a second-year teacher, was teaching a principles of engineering elective course for high school juniors. He described the reflective teaching practices in students’ evaluation piece for their final project. This project involved building a robot for commercial purposes using programming language and was the fourth project students worked on during the semester. Frank included at least three pieces of reflection during these projects. First, students needed to come up with collaboration rules for how they wanted to work as a team. Second, as part of the engineering process, students needed to evaluate their product and process. Third, they completed a self- and peer-evaluation based on the rubric and criteria they set up at the beginning of the project.

Frank also provided a rubric to explain his expectations and gave students almost three weeks to finish the process. Students worked in groups, but each individual had his or her own engineering notebook to document the project as part of assessment.
Frank’s curriculum and activities were based on a design from an educational organization promoting inquiry and engineering practices for students. After attending professional development during the summer, this was his second time teaching the course.

Both teachers were graduates from the MAT program. They had also both used reflective practices since their first year and learned how to use those reflective practices in the context of science teaching. However, their level of reflective awareness during our interview was different. I classified Mary’s interview as UR and Franks’ as CIR. For me, Frank’s reflective awareness made sense with his understanding of metacognition and his practices. For him, asking students to assess their process was highly connected with his method of understanding reflection based on data, evidence, and experiences. This could be because his own experiences of metacognition helped him make sense of these teaching practices. However, it seems to me that the most important element that helped Frank use metacognition seemed to be the fact that he received professional development about how to use metacognition as part of the engineering process.

**Learning to teach metacognition embedded in the science content.** Teachers need to teach metacognitive knowledge and skills if they want to develop students’ metacognition through the use of science and engineering practices. They need knowledge and experience with metacognition, knowledge of metacognitive teaching strategies, and experiences using these strategies in the science classroom in order to apply this expertise during their first years as teachers. Veenman et al. (2006) explained that
Teachers are absolutely willing to invest effort in the instruction of metacognition within their lessons, but they need the tools for implementing metacognition as an integral part of their lessons, and for making students aware of their metacognitive activities and the utility of those activities. (p. 10)

This was true for Mary and Frank. They both possessed metacognitive knowledge after their TEP, but they had experiences as an undergraduate student (in Mary’s case) and professional development (in Frank’s) modeling the use of metacognition in science content. Accordingly, new teachers must learn how to implement metacognition in the classroom and have prior experiences with metacognition embedded in science instruction.

Therefore, if students need to learn metacognition through explicit instruction and embedded content to help them transfer their knowledge across disciplinary contexts (Silver, 2013), new teachers also need to learn how to teach embedded metacognition so they can transfer that skill into their science classroom. Otherwise, new teachers will struggle to learn how to embed metacognition in science curriculum on their own, even using CCR.

The most influential element in helping science teachers use metacognition appears to be experience teaching science through metacognitive practices. If so, teachers may use these past experiences to guide their pedagogy despite their lack of teaching experience, just as Mary and Frank did. On the other hand, teaching experience might also help teachers transfer their knowledge about metacognition. Therefore, they might begin using more metacognitive teaching and overcome the typical concerns of beginning teachers: the appropriate class level, successful and engaging lessons, classroom
management, and being liked by learners (McGregor, 2011). In this way, teaching metacognition could be a tool for encouraging more innovative and creative strategies.

**Relationship to other researchers’ findings.** Russell and Martin (2014) concluded that new teachers teach based on what has been modeled to them rather than on what they have been told. If teachers need to model metacognitive thinking for students so that they can see it in action (White et al., 2009), this might also be true of teaching metacognition in their early careers. New teachers without experience using metacognition to teach science would be unlikely to attempt it (Russell & Martin, 2014). Mary and Frank both had experiences teaching science using metacognitive practices and consequently began incorporating metacognition and reflection in their classes as soon as they started teaching. This underscores the fact that teachers need experiences teaching metacognition in science content in order to incorporate it during their first years in the classroom.

Embedding metacognitive learning in science content can be important for both teachers and students. Schraw (1998) explained that metacognition was not domain-specific, as learners will transfer metacognitive skills to different settings and purposes. However, in order to develop metacognition, learners need explicit instruction and intentionality (Wilson & Conyers, 2013). Bixler (2011) explained that metacognition or self-monitoring does not develop spontaneously. Saab et al. (2012) found that students who received instruction in metacognition regulated their group activities more than those who did not receive it. Therefore, teachers must help students to “understand how they gain knowledge, to set goals for further improvement, and check their ongoing progress themselves” (Bixler, 2011, p. 78). Researchers seem to agree that the best way
to teach metacognition is by embedding it in science content to ensure the transferability and durability of knowledge (Georghiades, 2000; Lovett, 2013; Pintrich, 2002; Veenman et al., 2006). Pintrich (2002) and Georghiades (2000) suggested that teachers should use metacognitive knowledge explicitly by embedding it in their regular content-driven lessons, including metacognitive strategies in their plans, and explaining the usefulness of these strategies to students. This can help teachers generate an adequate environment to enhance reflective practices in the science classroom.

**Metacognitive teaching and assessment practices.** Mary and Frank were using reflective practices regularly in their science and principles of engineering classes. They understood the importance of giving students opportunities to practice and shared the belief that metacognitive experiences were difficult for students. However, they were convinced that these reflective practices were good for students and gave them relevance in their classroom by incorporating them into their grading systems.

While metacognitive teaching is often related to formative assessment strategies (Heritage, 2014; McGregor, 2011; Trauth-Nare & Buck, 2011) and its assessment is considered informal (Pintrich, 2002), Lederman et al. (2012) related formal assessment practices to the importance teachers give to elements such as scientific practices or the NOS. Therefore, teaching metacognition with intention requires considering it as part of course goals. It also involves investing instructional time, embedding metacognition in science content to support students’ skill development, and providing feedback and learning opportunities.

**Metacognition and beginning science teachers.** Almost all participants in this study reported learning about metacognition during their TEP. They described how some
of their professors used reflective practices while they were learning how to teach science. However, they were not often using reflective practices in their own classrooms. Moreover, most of them were involved in metacognitive processes through their schools, including submitting goals, collecting evidence, and having feedback sessions with their administrators. Participants also described mentoring experiences and reflective learning communities for collaboration, all of which can help new teachers. Russell and Martin (2014) explained that prospective teachers need to be directly challenged to confront their own misconceptions and work within their own process of conceptual change. This insight could also apply to teachers during their first years, when they are in a process of learning. Ideally, these mentoring and collaborative experiences would contribute to participants’ processes of conceptual change about teaching science.

Nevertheless, participants did not often use metacognitive teaching practices, even though they had been working on reflective processes as new teachers. Moreover, frequently they did not identify those reflective practices as metacognitive experiences. I concluded that this might be because of three main reasons: first, for participants, the term “metacognition” was something used during their studies, and they often noted that they did not hear about it anymore; second, as explained previously, the school context, teachers’ beliefs about teaching, and knowledge could be affecting their results; and third, this might also be because participants had not experienced learning science using metacognition and did not feel the need to do so. Therefore, they were unable make the transfer. Dewey (1910) explained that a reflective process starts with a problem. Posner, Strike, Hewson & Gertzog (1982) contended that conceptual change begins with dissatisfaction or discomfort with one’s current beliefs. If teachers believe that science
should be based on direct instruction or using cookbook lab practices, it will be difficult for them to adopt metacognitive teaching using scientific practices in their classroom. Not even teachers using critical conscious reflection can make those connections by themselves, and the process takes time. Teachers require specific knowledge about how to implement metacognitive teaching practices. They will need to transform that knowledge into experiences based on their goals and the strategies they have in their tool box as science teachers.

Conclusions

*Figure 5.1* Metacognitive teaching practices in beginning science teachers. Metacognitive teaching practices require knowledge and experiences of metacognition embedded in scientific practices within a context aligned to the epistemology of science.
Figure 5.1 summarizes the main findings of this study. In order to use metacognitive teaching strategies, beginning teachers require knowledge and experiences of metacognition that are embedded in science content or used with scientific or engineering practices. This knowledge and experience must also be framed in the context of how science generates new knowledge (the epistemology of science). Knowledge of metacognition should include planning, monitoring, and evaluating, concepts enhanced by the social aspect of metacognition. Experiences of metacognition for students should be conducted with intention and aligned with teachers’ curriculum, instruction, and assessment (formative and summative). Reflective practices can help beginning teachers improve their ability to implement metacognitive strategies. However, the school context, professional development, and teachers’ beliefs will also impact their choice of strategies for teaching science. Beginning teachers require more than just opportunities to reflect in order to use metacognitive strategies in their classroom.
CHAPTER 6: CONCLUSIONS AND IMPLICATIONS OF STUDY

In this final chapter I describe the implications and limitations of this study, provide recommendations for future research and teacher education programs, and offer conclusions.

Implications and Relevance of Study

The purpose of this research study was to help decrease the gap between research and metacognitive practices in the science classroom. Ben-David and Orion (2012) called for studies that relate theory with the reality of science classroom practice in the field of metacognition. This study aimed to provide a credible description of beginning science teachers’ practices and knowledge of metacognition. Moreover, researchers and educators frequently claim that teachers are metacognitive. However, there is a lack of detailed characterizations based on empirical qualitative or quantitative evidence of teachers’ knowledge and practices (Duffy et al., 2009). Having a better understanding of teachers’ knowledge and experiences of metacognition can help educators, school administrators, policy-makers, and science teachers know what is needed to promote metacognition among teachers and students.

Additionally, there is a call for empirical models that connect metacognition with the epistemology of science (Hofer & Sinatra, 2010). Much has been said about psychological metacognition, but studies of how to enhance reflection about the nature of science in the secondary classroom are still needed. Although this study was explorative in nature, it can contribute to generating future studies that confirm or reject these findings in relation to the epistemology of science.
Furthermore, there is a concern about the lack of knowledge or literature containing hands-on, user-friendly guides for teachers to implement metacognitive teaching practices (Silver, 2013). For this purpose, I constructed a diagram to explain the different levels of metacognitive teaching practices that might help educators and teachers explain the complexity of enacting metacognition, and could also be a base for evaluating and improving teaching practices. I also described several strategies to increase students’ metacognition and recommendations to help teachers become more reflective practitioners in their science instruction.

Moreover, the importance of this study is embedded in the importance of metacognition for learning. Learners (i.e., students in the science classroom or beginning science teachers) require metacognition as a tool to develop comprehension of their own learning, validate their knowledge, and provide elements to continue their learning process throughout their lives. Thus, using metacognition embedded in the science classroom can contribute to making science knowledge durable for students, promoting learning inside and outside the classroom, and developing the use of scientific practices to solve problems. Therefore, teachers need to be prepared not only to teach content knowledge and skills, but also to support students in the search for their own self-confidence and claims. Reflecting about teaching can help teachers improve their practice and become lifelong learners. Thus, understanding teachers’ knowledge and experiences of metacognition can provide insight into what teachers know and how teacher education programs and professional development can support these needs.

Finally, epistemic metacognition and the use of scientific practices may contribute to students’ scientific literacy. Metacognition can promote scientific literacy and positive
attitudes toward science (Adler et al., 2015). Schools need science teachers who work to develop more critical students. Therefore, it is important for them to also have knowledge and experiences of metacognition and to use more critical conscious reflection. Moreover, metacognition can enhance learning for all students and help teachers diversify their instruction based on students’ needs and interests (Heritage, 2014). This is especially important for low-achievement students (Kramarski et al., 2002; White et al., 2009). Having a better understanding of knowledge and experiences of metacognition in teachers may contribute directly to providing better opportunities to students historically at risk.

Teaching science as inquiry can be an effective context to provide opportunities for learning not only content, but also how to learn and generate new knowledge. I expect this study could provide ideas for applying metacognition in the science classroom, empowering students, and helping them become independent learners. This study could also be related to the aims and goals of educational documents, such as the NGSS, and to the importance of using science and engineering practices for metacognition. Metacognition and reflection can help teachers and students in learning science as well as in their daily lives. Reflective teachers and students can “make wise and thoughtful life decisions as well as to comprehend and learn better in formal educational settings” (Flavell, 1979, p. 910). In this way, the school can accomplish its final goal.

**Limitations of the Study**

This study has several possible limitations related to the complexity of the constructs of metacognition and reflection. Additionally, my experience as a novice
researcher and my cultural biases and experiences might also have affected the results. Finally, the exploratory nature of this study does not allow me to generalize the results.

Metacognition is a complex term and has been studied for several decades. It is often confused with other terms (e.g., self-regulation, reflection). Moreover, as part of a learning and thinking process, metacognition involves several variables and elements that interact with each other and are difficult to isolate or even fully explain. Therefore, it is a challenging concept to isolate. I also considered teachers’ comprehension and use of other terms, such as reflection, self-regulation, and the nature of science, to gain a better understanding of what participants knew about metacognition and especially their practices. I acknowledge that perhaps teachers knew more about metacognition and used it more frequently than I captured in this study.

I also explored teachers’ reflective practices to understand their experiences of metacognition. Reflection is also a complex term and could be used for several purposes in different contexts. Within the onion model (Korthagen & Vasalos, 2005), the content of teachers’ reflection includes personal identity, mission, and beliefs. I recognize that teacher’s identity and mission can have a strong influence on their knowledge and experiences of metacognition because of their relationship with reflective practices. Korthagen and Vasalos (2005) explained that these inner elements (i.e., identity, mission, beliefs) have a strong influence on the outer levels (i.e., competencies and behavior). Moreover, inner levels are related with deeper reflection and are more effective in terms of change and improvement. However, reflections about identity, missions, or deeper beliefs were outside the scope of this study. I focused on teaching competencies, which
are situated in the outer levels of the model, although I briefly explored some of the beliefs related to declarative knowledge that may have an impact on these competencies. Furthermore, because learning and metacognition are dynamic constructs, they are continuously changing and in transformation, informed by the experiences participants might have. Therefore, it was difficult to measure or fully explain metacognition based on my research instruments. For instance, to describe knowledge of metacognition I used a standardized questionnaire. Questionnaires cannot measure teachers’ experiences of metacognition or skills in using it, but they can help to describe metacognitive procedural knowledge (Clarebout, Elen, & Onghena, 2006). The purpose of using this instrument was to have some sort of measurement of participants’ knowledge of metacognition to compare with their experiences and try to find a connection. It was more likely that teachers would use metacognition if they had knowledge about it. However, I understand their knowledge and awareness could be more complex than what was demonstrated in the questionnaire.

Because I realized the complexity of metacognition as a construct, I decided to include qualitative data to gain a better understanding of teachers’ knowledge and practices of metacognition. While interviews were helpful to understand participants’ knowledge and practices of metacognition, what teachers think they do does not always align with what they actually do (Osborne, 2014). For this reason, I used classroom observations form a larger study to confirm participants’ self-reported practices. However, I may have missed or been unable to observe the full range of practices participants described. Moreover, because I used a limited sample of observations, it may
not be possible to generalize these findings for other secondary science teachers under different circumstances.

Besides self-reporting, there are other methodologies for studying teachers’ metacognition. For example, this study did not include the thinking process related with teachers’ decision-making after using metacognitive teaching practices or their awareness of cognition. To understand what was happening with teachers’ thinking inside the classroom, it would be necessary to employ other research strategies like journaling or thinking-aloud protocols. These research activities were not part of the scope of the present study.

As another limitation, the sample size of the MAIT survey and the convenience sample used for the qualitative phase of the study did not allow me to generalize the results of this work outside the population studied. Moreover, despite the power analysis I conducted for this study design, the quantitative results were not significant. This could potentially change with a larger sample. However, due to restrictions on time and resources, I was unable to reach more participants. Since I considered this study exploratory in nature from the beginning, my purpose was to provide a description of beginning secondary science teachers’ knowledge and practices of metacognition as a starting point for future research studies and interventions. This project could serve as a diagnosis for how this group of teachers might understand and use metacognition that may be transferable to similar teaching contexts and populations.

Finally, I also realize that my position as a researcher was a limitation for this study. This was my first time analyzing reflective practices, so perhaps my knowledge and dispositions toward participants affected my coding. I acknowledge that I did not use
a standardized instrument or episodes to code these reflections, instead using descriptions of teaching practices to classify the level of reflection. Collin et al. (2013) recommended using proven instruments and evaluating them constantly to conduct empirical studies of reflective practice. Although Cartwright’s (2013) classification of reflective practices was similar to Larrivee’s (2008a) standardized instrument, I decided to use Cartwright’s (2013) because it seemed simpler (three categories instead of four) and more appropriate for an exploratory study than Larrivee’s standardized tool. Furthermore, Larrivee’s tool emphasized reflection about social justice and power relationships, topics that were outside the scope of my interviews.

Additionally, my own knowledge and experiences of metacognition and metacognitive teaching practices could have affected the focus of my questions and my understanding of participants’ answers. I am also aware I come from a different background and culture than participants, which might influence how I perceive reality. However, this could also help me act as a “professional stranger” (Agar, 1996/1982), finding rich points of information as a result of my position as an outsider.

**Recommendations for Future Research**

Because this multi-methods research study was exploratory, the findings will require confirmatory studies to be generalizable. Therefore, collecting more evidence from beginning science teachers could strengthen the findings and help confirm study claims. A larger sample size could also potentially help find a more significant relationship between teaching experience and metacognitive awareness and could confirm whether the level of teacher education program enhances teachers’ knowledge of metacognition. Since participants in this study also frequently described negative
attitudes from students toward metacognitive practices, it would be instructive to ask students directly about their perceptions of reflective and metacognitive practices in the science classroom and their impact on learning.

Because metacognition is most effective when embedded in science content, in-depth descriptions of successful cases like Mary’s undergraduate geology course could also illuminate recommendations for similar courses. These courses could have a fundamental influence on new science teachers’ practices and beliefs about teaching science. It would also be interesting to conduct a similar study with experienced and cooperating teachers serving as models for pre-service teachers. Developing cooperating teacher interventions in order to increase new teachers’ knowledge and practices of metacognitive teaching seems promising. Additionally, professional development featuring metacognition for new teachers could contribute to their knowledge and practices of metacognition, since they do not seem to be receiving this development in their home schools.

Finally, practitioners could develop a manual with metacognitive teaching strategies related to science and engineering practices. Additional research could be conducted to create a more exhaustive list of practices and provide educators and science teachers with easy-to-use metacognitive teaching practices. This could also help teachers overcome the belief that metacognition is a complicated construct or a scholarly term with no use in the science classroom.

**Recommendations for Teacher Education Programs**

Findings from this study reveal that teacher education programs can have a fundamental role in the knowledge and experiences of metacognition for beginning
science teachers. For almost all participants, a TEP was their sole source of knowledge about metacognition and metacognitive teaching practices. I acknowledge that the range of information and skills deemed necessary for developing effective science teachers is already too broad, and the time and resources in TEPs are limited. Thus, I suggest working on small interventions that could give science teachers a better understanding of metacognition.

It seems that the definition “thinking about thinking” is a popular one, as almost all teachers identified it with metacognition. However, this definition can also cause misunderstandings about what metacognition looks like inside the classroom. Therefore, I would suggest emphasizing Schraw’s (1989) classification of the elements of metacognition as planning, monitoring, and evaluation and practicing them as part of the teaching methods course. For example, this could be implemented by asking teachers to set up goals at the beginning of the course, look for strategies to monitor those goals, and assess their development at the end of the semester. It is also important for science teaching methods instructors to explain and make teachers aware when a metacognitive strategy has been used and discuss how it could help learners’ understanding.

Furthermore, teacher educators should promote an open-to-learning environment based on the nature of science in the teaching methods course. For example, this course could promote principles like creativity, openness to ideas, listening, and the importance of learning from mistakes and collaboration. These principles should be featured explicitly and with intention. TEPs can thus promote a context in which pre-service teachers develop deeper reflections as well as an example of how a science classroom should be conducted.
Methods course teachers could also explicitly ask pre-service teachers to include metacognitive practices in the lesson plans they develop. To this end, I proposed a list of research-based metacognitive practices that could be shared with pre-service teachers to give them ideas for the classroom. Additionally, the figure I created to describe metacognitive practices could help teachers develop a better understanding of practices they could use and how they might assess and promote thinking through a more sophisticated, student-centered, collaborative approach. These two tools (the list of practices and the diagram) could ideally help student teachers identify options for strategies to use with their students.

Moreover, Windschitl and Stroupe (2017) contend that “responsive teaching can only be understood by designing and enacting instruction with learners” (p. 257). Therefore, they suggest that TEPs should provide PSTs with opportunities to prepare and enact lessons, and to enact them with their peers (playing the role of students) to provide supportive conditions. These practices could work as a rehearsal of lessons where PSTs should respond to students’ thinking and also could serve to provide them with feedback and opportunities to analyze and reflect about their teaching. The authors also suggest video-analysis and micro-teaching strategies to help teachers not just to use reflective practices to assess their teaching, but also to learn how to use and elicit students’ thinking to teach science.

Using this same idea of enacting instruction with learners, Windschitl and Thompson (2006) suggested the use of inquiry projects as part of the strategies in the methods courses, in which PSTs use their journals to reflect about how they generated ideas and the pedagogical implications of this strategy to support students’ thinking.
Reflective practices are also an important element of teacher education programs, and teacher educators can dedicate time to explaining how pre-service teachers might deepen their reflections. Including the levels of reflective awareness could be a useful strategy. Templates such as “what, so what, and now what” could also help teachers to guide their reflections and use theories, power relations, or social justice issues as analytical lenses.

**Conclusions**

Based on this exploratory multi-methods study, I conclude that participants had a high awareness or knowledge of metacognition and could relate it to thinking as scientists. However, their knowledge did not significantly increase during their first years of teaching, and they often did not know how to enact metacognitive teaching using science and engineering practices. What they learned about metacognition after their TEPs was what informed their teaching practices, and this term was not often used in school settings. Therefore, participants believed it was a complex and scholarly term that might not be necessary to teach, especially during their early careers. Most of them were more concerned with developing expertise in teaching science content and believed that elements like metacognition would come later, as they gained teaching experience. On the other hand, teachers were familiar with reflection and considered it a more manageable construct to use. Moreover, participants recognized metacognition as a double cycle of thinking or reflecting about learning. However, they held some misconceptions about how to enact this double cycle, especially within scientific practices. They also viewed this construct as difficult for students.
Teachers in this study required knowledge of metacognition in order to transform it into experiences of metacognition, and vice versa. Knowledge informs practices and experiences enrich knowledge (Flavell, 1989). For instance, participants understood metacognition as an individual reflection and primarily as self-evaluation. Therefore, they used individual metacognitive teaching practices as formative assessment for science instruction. These participants often did not recognize the monitoring and planning tasks of metacognition or the role of collaboration in enhancing metacognitive teaching. They also did not frequently require students to set up goals or monitor those goals, although many of them set, monitored, and assessed their own goals as part of their professional evaluation. They did not transfer their experiences outside the classroom into metacognitive teaching practices.

Experiences of metacognition such as reflective practice can help teachers develop experiential wisdom by relating knowledge and experiences. However, reflective practices are multidimensional. Experiences, beliefs, and a context based on the epistemology of science might help teachers improve their reflective awareness as experiences of metacognition. However, I found no evidence that these experiences increased participants’ knowledge of metacognition or their use of metacognitive teaching practices in the classroom, at least during their early years as teachers. On the other hand, knowledge and experience can help teachers deepen their reflective awareness to improve their teaching.

Furthermore, participants may also have been receiving exemplary and collaborative experiences of metacognition as part of professional development and their own reflective practices. However, it was not clear whether conscious reflection
translated into more metacognitive teaching practices. Conscious critical reflection requires thinking about theories of teaching and learning. Therefore, knowledge of metacognitive teaching is needed to develop awareness and experiences of metacognition. Nonetheless, modeling knowledge and experiences of complex metacognitive teaching practices in science content seemed to be the most effective method for participants to appreciate the importance of including them in their science instruction.

As this study was explanatory, findings are not generalizable. More research is needed to confirm the claims proposed. Ultimately, it is important to develop interventions, professional development, and easy-to-use metacognitive teaching strategies for new and experienced teachers, especially for cooperating teachers who can serve as models and have an impact on new teachers’ knowledge and practices.
REFERENCES


current literature. *Reflective Practice*, 16(1), 123–141.


Lovett, M.C. (2013). Make exams worth more than the grade. In M. Kaplan, N. Silver, D. Lavaque-Manty, & D. Meizlish (Eds.), Using reflection and metacognition to improve student learning (pp. 18-52). Sterling, Virginia: Stylus Publisher, Inc.


Silver, N. (2013). Reflective pedagogies and the metacognitive turn in college teaching. In M. Kaplan, N. Silver, D. Lavaque-Manty, & D. Meizlish (Eds.), *Using Reflection and Metacognition to Improve Student Learning* (pp. 1-17). Sterling, VA: Stylus Publisher, Inc.


Appendix A

NGSS Scientific and Engineering Practices

Practices of science and engineering essential for all students to learn (NGSS Lead States, 2013):

1. Asking questions (for science) and defining problems (for engineering).
2. Developing and using models.
3. Planning and carrying out investigations.
4. Analyzing and interpreting data.
5. Using mathematics and computational thinking.
6. Constructing explanations (for science) and designing solutions (for engineering).
7. Engaging in argument from evidence.
8. Obtaining, evaluating, and communicating information.
Appendix B

Conceptual Differences Between Metacognition, Self-regulation, and Self-regulated Learning

Table 1

|                         | Metacognition                                                                 | Self-regulation                                                                                      | Self-regulated learning                                                                 |
|-------------------------|------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|
| **Origin**              | 1970s in John Flavell’s writings, supported in Jean Piaget’s theories        | 1970s in Albert Bandura’s writings                                                                  | 1980s and gained prominence in the 1990s, especially in hypermedia environments       |
| **Description**         | Thinking about thinking                                                      | Reciprocal determinism of the environment on the person, mediated through behavior                  | Self-regulation in academic settings. Incorporates aspects of both metacognition and self-regulation on learner monitoring |
| **Orientation**         | Cognition (the mind of the individual)                                       | Behavioral and emotional regulation                                                                 | Cognition and behavioral regulation on learning                                         |
| **Focus**               | Awareness of cognition                                                      | Human actions as a result of interaction of the person with the environment                         | Interaction of cognitive-motivational and contextual factors.                           |
| **Labeled as**          | *Endogenous constructivism* (i.e., reflective abstraction of new or existing cognitive structures) | *Exogenous constructivism* (i.e., derivation of knowledge from the environment)                     | *Dialectical constructivism* (i.e., the integration of endogenous and exogenous constructivism) |
| **Frameworks**          | Cognitive theories                                                           | Neobehaviorism and empiricism                                                                     | Integrated theory of learning                                                        |
| **Emphasis**            | Learner development                                                          | Learner-environment reciprocal interactions                                                        | Learner-environment interactions                                                     |
| **Monitor or control**  | Cognition                                                                    | Behavior, cognition, and motivation                                                                | Behavior, cognition, and motivation                                                   |
Appendix C

IRB Approval Letter

Official Approval Letter for IRB project #16260 - New Project Form
August 16, 2016 - Official Approval Letter

Ana Margarita Rivera Arias
Teaching, Learning and Teacher Education
2221 5th street #2 Lincoln, NE 68503

Elizabeth Lewis
Teaching, Learning and Teacher Education
HES 2110- UNL- 08388-9595

IRB Number: 201003620EX
Project ID: 12106
Project Title: Bonding Ideas about Inquiry: Exploring Knowledge and Practices of Metacognition in Beginning Secondary Science Teachers

Dear Ana Margarita:

This letter is to officially notify you of the certification of exemption of your project for the Protection of Human Subjects. Your proposal is in compliance with this institution's Federal Wide Assurance 00001200 and the DHHS Regulations for the Protection of Human Subjects (45 CFR 46) and has been classified as exempt.

You are authorized to implement this study as of the Date of Final Exemption: 8/15/2016

- Review conducted using exempt categories 1 and 2 at 45 CFR 46.101
- Funding: NA

** You are approved to conduct interviews with selected participants at Gering Public Schools, Boone Central Schools, Fremont Public Schools, Columbus Public Schools, Elkhorn Public Schools, Scottsbluff-Snyder Community Schools, Lincoln Public Schools, Omaha's Henry Doorly Zoo and Aquarium, Lourdes Central Catholic School, Beatrice Public Schools, Omaha Public Schools, and Louisville Middle School.

** As a reminder, school district permission letters/emails will need to be submitted before you conduct additional interviews and class observations. School can be added to your approved list of sites on a case by case basis as permission letters are received by the IRB office. Once you have determined which school districts will be involved and have obtained official site permission from the districts signatory official, please forward these documents to lmesanich@unl.edu. However, if you will be working with UPS, please submit a change request for us to forward to Dr. Leslie Eastman for UPS site permission.

We wish to remind you that the principal investigator is responsible for reporting to this board any of the following events within 48 hours of the event:

- Any serious event (including on-site and off-site adverse events, injuries, side effects, deaths, or other problems) which in the opinion of the local investigator was unanticipated, involved risk to subjects or subjects, and was related to the research procedures;
- Any serious adverse event that changes the risk/benefit ratio of the research;
- Any breach in confidentiality or compromise in data privacy related to the subject or subject;
- Any complaint of a subject that indicates an unexpected risk that cannot be resolved by the research staff.

This project should be conducted in full accordance with all applicable sections of the IRB Guidelines and you should notify the IRB immediately of any proposed changes that may affect the exempt status of your research project. You should report any unanticipated problems involving risks to the participants or others to the board.

If you have any questions, please contact the IRB office at 402-472-6585.

Sincerely,

Becky R. Freeman

Becky F. Freeman, CF
for the IRB

University of Nebraska-Lincoln Office of Research and Economic Development nucgrant@unl.edu
Appendix D

Consent Forms

Consent form for online survey

You are invited to participate in a web-based online survey on metacognitive awareness. The purpose of this study is to describe the metacognitive knowledge and practices of beginning science teachers after completing a teacher education program. This project will study early teaching experience.

This is a research project being conducted by Ana Rivero, a graduate student at the University of Nebraska-Lincoln pursuing her Ph.D. in Educational Studies, and her advisor Dr. Beth Lewis. The survey should take approximately 20 minutes to complete.

Participation and Freedom to Withdraw
Your participation in this survey is voluntary. You may refuse to take part in the research or exit the survey at any time without penalty. You are free to decline to answer any particular question you do not wish to answer for any reason. If you withdraw from the survey, any data that has been collected from you will be destroyed at that time and will not be used in any presentations or reports generated from the data.

Benefits
Participating in this research will inform and provide opportunities to the researcher to have a better understanding of the knowledge and practices of metacognition in beginning science teachers. It will also inform the district and science education leaders about preparing and supporting early career science teachers.

Risks and/or Discomforts
There are no known risks or discomforts associated with this research.

Confidentiality
Your survey answers will be sent to a link at Qualtrics where data will be stored in a password-protected electronic format. Qualtrics does not collect identifying information such as your name, email address, or IP address. No names or identifying information would be included in any publications or presentations based on these data, and your responses to this survey will remain confidential.

At the end of the survey you will be asked if you are interested in participating in an additional interview (by phone, in person, or via email).
Contact
If you have questions at any time about the study or the procedures, you may contact the investigator (Ana M. Rivero) via phone at 402 480 0033 or via email at arivero@husker.unl.edu or Dr. Beth Lewis at elewis3@unl.edu.

If you feel you have not been treated according to the descriptions in this form, or you have any questions, concerns, or complaints that you wish to address to someone other than the investigator, you may contact the University of Nebraska-Lincoln Institutional Review Board at 402-472-6965 or irb@unl.edu.

Electronic consent
Please select your choice below. You may print a copy of this consent form for your records. Clicking on the “Agree” button indicates that

- You have read the above information
- You voluntarily agree to participate
- You are 19 years of age or older

☐ Agree

☐ Disagree

Please write your name: __________________________________

Approval to use data
You have been participating in the research project “Longitudinal Evaluation of Novice Science Teachers to Determine Sources of Effective Teaching.” The researcher would like to use the following data from this study:

1. Your classroom observation and interview records
2. Your demographic, school, endorsements, and employment information
3. Your self-efficacy survey and MOSART tests data.

All information that could identify you will be kept strictly confidential. These data will help to analyze knowledge and practices of metacognition. The analysis and conclusions may be published in journals or presented at meetings; pseudonyms will be used for individuals and institutions, and the data from individuals will be compiled and reported at the group level. No honorarium will be provided. To allow the researcher to use these data is completely voluntary.

☐ Yes, I allow the researcher to use my data from the project “Longitudinal Evaluation of Novice Science Teachers to Determine Sources of Effective Teaching.”

☐ No, I do not allow the researcher to use my data from the project “Longitudinal Evaluation of Novice Science Teachers to Determine Sources of Effective Teaching.”
Identification of Project
Bonding ideas about inquiry: Exploring knowledge and practices of metacognition in beginning secondary science teachers

Introduction
The purposes of this form are: (1) to provide you, as a prospective research study participant, information that may affect your decision as to whether or not to participate in this research; and (2) to record the consent of those who agree to be involved in the study.

Purpose of the Research
The goal of this study is to describe the metacognitive knowledge and practices of beginning science teachers after the completion of a teacher education program. Data will be gathered from surveys, questionnaires, and interviews. This project will study early teaching experience.

Procedures
If you agree to participate in this study, you will:
• take a metacognitive awareness survey;
• take an open-ended questionnaire about the nature of science;
• provide demographic information;
• participate in an interview to document your metacognitive knowledge and self-reported practices. These interviews will be conducted in person, by phone, or via teleconference, depending upon the teacher’s preference, availability of internet connection, and geographic location. The interviews will be audio recorded; and
• allow the researcher to use your data from the study “Longitudinal Evaluation of Novice Science Teachers to Determine Sources of Effective Teaching” (observations and interview records, data collected from surveys, employment and school information).

The metacognitive awareness survey and demographic information should take about twenty minutes to complete. The open-ended questionnaire about the nature of science will take about 30 minutes. The researcher will coordinate with you to arrange the interview meeting. The interview will take 30 to 45 minutes. In total, your participation in this project will require about two hours of your time.

Risks and/or Discomforts
There are no known risks or discomforts associated with this research.

Benefits
Participating in this research will inform and provide opportunities for the researcher to gain a better understanding of the knowledge and practices of metacognition in beginning science teachers. It will also inform the district and science education leaders about preparing and supporting early career science teachers.

Confidentiality
Any information obtained during this research that could identify you will be kept strictly confidential. The data will be stored in a locked cabinet in the researcher’s office and will only be seen by the researcher and her advisor during the study and for three years after analyses from the study are complete. The information obtained in this study may be published in journals or
presented at meetings; pseudonyms will be used for individuals and institutions, and the data from individuals will be compiled and reported at the group level.

**Compensation**

Participation in this research is voluntary. No honorarium will be provided. The researcher will compensate participants with a small present (e.g. chocolate, a gift certificate) to express gratitude for your generous participation.

**Opportunity to ask Questions**

You may ask any questions concerning this research/evaluation and have those questions answered before agreeing to participate or during the study. Or you may contact the investigator at any time: Ana Rivero (arivero@huskers.unl.edu or 402-480-0033) or Dr. Beth Lewis (elewis3@unl.edu). You may also contact the University of Nebraska-Lincoln’s Institutional Review Board at (402) 472-6965 if you have any questions about your rights as a research participant.

**Freedom to Withdraw**

Participation in this study is completely voluntary. It is okay for you to say NO. Even if you say YES now, you are free to say NO later and withdraw from the study at any time. Your decision will not affect your relationship with the researcher or the University of Nebraska-Lincoln or otherwise cause a loss of benefits to which you might otherwise be entitled. If you withdraw from the study, any interview data that has been collected from you will be destroyed at that time and will not be used in any presentations or reports generated from the data.

**Consent, Right to Receive a Copy**

This form explains the nature, demands, benefits, and potential risks of the project. By signing this form, you agree knowingly to assume any risks involved. Remember, your participation is voluntary. You may choose not to participate or to withdraw your consent and discontinue participation at any time without penalty or loss of benefit. In signing this consent form, you are not waiving any legal claims or rights. A copy of this consent form will be given to you.

The University of Nebraska-Lincoln wants to know about your research experience. This 14-question, multiple-choice survey is anonymous; however, you can provide your contact information if you want someone to follow-up with you. This survey should be completed after your participation in this research. Please complete this optional online survey at: https://ssp.qualtrics.com/SE/?SID=SV_aVvlNCli0U1vse5n.

**Please initial:**

____ I agree to be audio recorded during interviews.

**Signature of Participant**

<table>
<thead>
<tr>
<th>Participant's Signature</th>
<th>Printed Name</th>
<th>Date</th>
</tr>
</thead>
</table>
INSERVICE TEACHER INFORMED CONSENT FORM (Complete)

Identification of Project
Bonding ideas about inquiry: Exploring knowledge and practices of metacognition in beginning secondary science teachers.

Introduction
The purposes of this form are: (1) to provide you, as a prospective research study participant, information that may affect your decision as to whether or not to participate in this research; and (2) to record the consent of those who agree to be involved in the study.

Purpose of the Research
The goal of this study is to describe the metacognitive knowledge and practices of beginning science teachers after completing a teacher education program. Data will be gathered from surveys, interviews, classroom observations, and artifact analysis. This project will study teachers of early (0-3 years) levels of teaching experience.

Procedures
If you agree to participate in this study, you will:

- take a metacognitive awareness survey;
- take an open-ended questionnaire about the nature of science;
- provide demographic information;
- participate in an interview to document your metacognitive knowledge and self-reported practices. These interviews will be conducted in person, by phone, or via teleconference, depending upon the teacher’s preference, availability of internet connection, and geographic location. The interviews will be audio recorded;
- allow the researcher to use your data from the study “Longitudinal Evaluation of Novice Science Teachers to Determine Sources of Effective Teaching” (observations and interview records, data collected from surveys, employment and school information), and
- be observed (in person) for a total of two weeks of classroom observations; and
- provide electronic or paper copies of instructional materials (such as handouts, lab reports, quizzes, projected slides).

The metacognitive awareness survey and demographic information should take about 20 minutes to complete. The open-ended questionnaire about the nature of science will take about 30 minutes. The researcher will coordinate with you to arrange classroom observations. I will observe lessons you would normally teach for two weeks in a row. The interview will take 30 to 45 minutes. In total, your participation in each year of this project will require about two hours of your time.

Risks and/or Discomforts
There are no known risks or discomforts associated with this research.

Benefits
Participating in this research will inform and provide opportunities to the researcher to gain a better understanding of the knowledge and practices of metacognition in beginning science teachers. It will also inform the district and science education leaders about preparing and supporting early career science teachers.

Confidentiality
Any information obtained during this research that could identify you will be kept strictly confidential. The data will be stored in a locked cabinet in the researcher’s office and will only be seen by the researcher and her advisor during the study and for three years after analyses from the study are complete. The information obtained in this study may be published in journals or presented at meetings; pseudonyms will be used for individuals and institutions, and the data from individuals will be compiled and reported at the group level.

**Compensation**

Participation in this research is voluntary. No honorarium will be provided. The researcher will compensate participants with a small present (e.g., chocolate, a book, a gift certificate) to express gratitude for your generous participation.

**Opportunity to ask Questions**

You may ask any questions concerning this research/evaluation and have those questions answered before agreeing to participate in or during the study. Or you may contact the investigator at any time: Ana Rivero ([arivero@huskers.unl.edu](mailto:arivero@huskers.unl.edu) or 402-480-0033) or Dr. Beth Lewis ([elewis3@unl.edu](mailto:elewis3@unl.edu)). You may also contact the University of Nebraska-Lincoln’s Institutional Review Board at (402) 472-6965 if you have any questions about your rights as a research participant.

**Freedom to Withdraw**

Participation in this study is completely voluntary. It is okay for you to say NO. Even if you say YES now, you are free to say NO later, and withdraw from the study at any time. Your decision will not affect your relationship with the researcher or the University of Nebraska-Lincoln or otherwise cause a loss of benefits to which you might otherwise be entitled. If you withdraw from the study, any interview data that has been collected from you will be destroyed at that time and will not be used in any presentations or reports generated from the data.

**Consent, Right to Receive a Copy**

This form explains the nature, demands, benefits, and potential risks of the project. By signing this form, you agree knowingly to assume any risks involved. Remember, your participation is voluntary. You may choose not to participate or to withdraw your consent and discontinue participation at any time without penalty or loss of benefit. In signing this consent form, you are not waiving any legal claims or rights. A copy of this consent form will be given to you.

The University of Nebraska-Lincoln wants to know about your research experience. This 14-question, multiple-choice survey is anonymous; however, you can provide your contact information if you want someone to follow-up with you. This survey should be completed after your participation in this research. Please complete this optional online survey at: [https://ssp.qualtrics.com/SE/?SID=SV_aVvlNCf0U1vse5n](https://ssp.qualtrics.com/SE/?SID=SV_aVvlNCf0U1vse5n).

**Please initial:**

____ I agree to be audio/video recorded during interviews and classroom observations.

**Signature of Participant**

<table>
<thead>
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<th>Participant's Signature</th>
<th>Printed Name</th>
<th>Date</th>
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</thead>
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Appendix E

Participants’ Demographic Information in the Qualitative Strand of the Study

Table 1

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<th>Education</th>
<th>Gender</th>
<th>Ethnicity</th>
<th>Years of teaching</th>
<th>Level</th>
<th>SES School (% FRL*)</th>
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<td>Jean</td>
<td>31-35</td>
<td>Insect science, minor in biology and psychology (UG) Science education (MAT)</td>
<td>Female</td>
<td>Caucasian or Western European</td>
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<td>4</td>
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*FRL: Free and reduced lunch*
## Table 2

**Participants’ Teaching Experience**

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<th>Other experiences</th>
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<tr>
<td>Paula</td>
<td>Honors biology for freshmen and sophomores; physical science for freshmen</td>
<td>Day camps with school-age students during UG</td>
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</table>
| Elsa    | Physical science for freshmen; chemistry for juniors | Worked in a lab (genetics) for a year before her MAT  
First year at this school |
| Frank   | Engineering courses (Project “Lead the Way”) and physics to juniors and seniors in a vocational academy | Taught introductory physics and calculus during UG  
Summer camp counselor for a missionary course and the Massachusetts Institute of Technology (MIT) |
| Gina    | Chemistry for juniors; physical science for juniors and seniors | Taught geoscience last year; tutored high school students; softball coach |
| Kate    | Biology for sophomores; chemistry for sophomores and juniors; anatomy and physiology for juniors and seniors; microbiology for seniors; standard science for juniors | First year at this school; taught at another school the previous year |
| Lucy    | 8th grade zoology (elective) for a Magnet Middle School Zoo Academy partnership | Educational programs and summer institute in a zoo |
| Pam     | Physical and general science for sophomores; applied science for juniors; physics for seniors; anatomy and physiology for sophomores and seniors | Teacher in the military; second year teaching at this school |
| Steve   | Earth and space science and physical science for freshmen | Worked three and a half years as broadcast meteorologist before starting the MAT |
| Henry   | Physical and natural science for freshmen; physics | Grew up on a farm; part of a leading group organizing PD at his school |
| David   | Biology for sophomores; zoology (elective) for juniors and seniors | Research in biology and looking for funding in a Latin-American country; construction |
| Emma    | 6th grade science | Worked in a research lab during her UG |
| Betty   | Earth science for freshmen; chemistry for juniors | Started a wildlife ecology graduate program and did some research for the university; helped in a Social Service Agency; taught biology for four years; cross country and track coach in the spring |
| Jean    | Biology (regular and accelerated) for sophomores | Has been teaching at this school for three years |
| Matt    | 6th, 7th, and 8th grade science | Worked 11 years as a scientist; fifth year teaching the same courses |
| Mary    | 6th grade science (MS); biology (regular and advanced) for sophomores and juniors | Fifth year working at this school |
Appendix F

Number of Classroom Observations Conducted for Each Participant in the Longitudinal Study

Table 1

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* Student teacher supervisor

NA: not applicable; NIS: not in the study; ST: student teaching
Appendix G

Metacognitive Awareness Inventory for Teachers (MAIT) (Balcikanli, 2011)

The MAIT is a list of 24 statements. There are no right or wrong answers in this list of statements. It is simply a matter of what is true for you. Read every statement carefully and choose the one that best describes you. Thank you very much for your participation.

1= Strongly Disagree 2= Disagree 3= Neutral 4= Agree 5= Strongly Agree

<p>| 1. I am aware of the strengths and weaknesses in my teaching. | 1 | 2 | 3 | 4 | 5 |
| 2. I try to use teaching techniques that worked in the past. |   |   |   |   |   |
| 3. I use my strengths to compensate for my weaknesses in my teaching. |   |   |   |   |   |
| 4. I pace myself while I am teaching in order to have enough time. |   |   |   |   |   |
| 5. I ask myself periodically if I meet my teaching goals while I am teaching. |   |   |   |   |   |
| 6. I ask myself how well I have accomplished my teaching goals once I am finished. |   |   |   |   |   |
| 7. I know what skills are most important in order to be a good teacher. |   |   |   |   |   |
| 8. I have a specific reason for choosing each teaching technique I use in class. |   |   |   |   |   |
| 9. I can motivate myself to teach when I really need to teach. |   |   |   |   |   |
| 10. I set my specific teaching goals before I start teaching. |   |   |   |   |   |
| 11. I find myself assessing how useful my teaching techniques are while I am teaching. |   |   |   |   |   |
| 12. I ask myself if I could have used different techniques after each teaching experience. |   |   |   |   |   |
| 13. I have control over how well I teach. |   |   |   |   |   |
| 14. I am aware of what teaching techniques I use while I am teaching. |   |   |   |   |   |
| 15. I use different teaching techniques depending on the situation. |   |   |   |   |   |
| 16. I ask myself questions about the teaching materials I am going to use. |   |   |   |   |   |
| 17. I check regularly to what extent my students comprehend the topic while I am teaching. |   |   |   |   |   |
| 18. After teaching a point, I ask myself if I’d teach it more effectively next time. |   |   |   |   |   |
| 19. I know what I am expected to teach. |   |   |   |   |   |
| 20. I use helpful teaching techniques automatically. |   |   |   |   |   |
| 21. I know when each teaching technique I use will be most effective. |   |   |   |   |   |
| 22. I organize my time to best accomplish my teaching goals. |   |   |   |   |   |</p>
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<thead>
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<th></th>
<th></th>
<th></th>
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</thead>
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<tr>
<td>23. I ask myself questions about how well I am doing while I am teaching.</td>
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<td></td>
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<tr>
<td>24. I ask myself if I have considered all possible techniques after teaching a point.</td>
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Appendix H

Interview Protocols

Initial interview protocol (Version 1, 08/05/2016)

1. What are you teaching? Do you have a general goal for your students as a science teacher? What would you like your students to develop after your course?

2. What do you understand as scientific thinking?

3. Do you think it is important to promote scientific thinking in a science classroom? Why? How? Can you give an example of how do you do it? How do you assess whether you are developing it?

4. What do you understand as metacognition?

5. Why do you think it is important to develop students’ metacognition in your science classroom?

6. Do you use metacognition in your science class with your students? Could you list and describe the practices of metacognition you use?

7. When do you use metacognition in your classroom?

8. Do you find any relationship or connection between scientific thinking and metacognition? If so, how are they connected?

9. Do you find difficulties in integrating metacognitive practices in your science lessons? Is there something that promotes your use of metacognition in the classroom?

10. Do you use metacognition outside your classroom? How? When?

11. What do you know about how science generates new knowledge or the nature of science?
12. Do you consider it important to think or reflect about the nature of science with your students? If you do, when is it important to do it? How do you do it?
13. Do you find difficulties discussing the nature of science with your students?
14. What could help you include the nature of science in your classroom?
15. Do you think about the nature of science outside your classroom? How?
16. Do you reflect about your teaching practice outside the classroom? Why? How? When?
17. Do you think there is something that helps you or prevents you from reflecting about your teaching practice?
18. What recommendations would you give to new teachers about the use of reflection inside or outside the science classroom?

Final interview protocol (Version 6, 10/11/2016)

1. What are you teaching this year (subjects, grade)?
2. Tell me a little about your background. What did you study to become a science teacher?
3. How did you decide to become a science teacher?
4. What do you consider as effective science teaching? Describe your ideal science lesson. Is this something you have done or that you would like to do?
5. How do you know when you are teaching science effectively?
6. When do you decide you need to change something related to your teaching?
7. How often do you modify your teaching or your teaching strategies? How do you do so? Do you have an example?
8. How do you know or discover the teaching strategies you would like to incorporate into your teaching?

9. What are the outcomes you expect from students after your course?

10. Do you set specific goals regarding classroom strategies or behaviors? When? How?

11. How do you follow up on your goals? How do you know you accomplished them? Do you receive feedback about your teaching?

12. Do you have someone help you to assess your goals and give you feedback about your teaching?

13. What do you know about the following terms:

   Scientific thinking
   Metacognition
   Self-regulation
   Student reflection
   Nature of science

14. Do you find connections among them?

15. How did you learn about these terms?

16. Do you hear about them in your school environment? Which one? Where? How?

17. Do you use these concepts in your science classroom? How?

18. Do you find difficulties using them? Is there something that prevents you from using them?

19. Is there something that helps or supports your use of these concepts in the classroom?
20. Do you ask students to set goals for themselves? Why or why not?

21. Do you think or reflect about your teaching practice inside or outside the classroom? Both? Why? How? When?

22. Do you consider yourself a reflective teacher? Why or why not?

23. Do you think there is something that helps you or prevents you from reflecting about your teaching practice?

24. What recommendations would you give to new science teachers related to what we discussed in this interview, based on your experience?
### Appendix I

**Participants’ Interview Dates and Lengths**

Table 1

<table>
<thead>
<tr>
<th>Participant</th>
<th>Time</th>
<th>Date</th>
<th>Participant</th>
<th>Time</th>
<th>Date</th>
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<td>Henry</td>
<td>43’38”</td>
<td>09/21/2016</td>
<td>Mary</td>
<td>54’01”*</td>
<td>11/09/2016</td>
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<tr>
<td>Jean</td>
<td>49’06”</td>
<td>10/03/2016</td>
<td>Gina</td>
<td>48’22”</td>
<td>11/10/2016</td>
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<td>David</td>
<td>67’07”</td>
<td>10/13/2016</td>
<td>Emma</td>
<td>52’10”</td>
<td>11/10/2016</td>
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<td>Lucy</td>
<td>77’43”</td>
<td>10/18/2016</td>
<td>Elsa</td>
<td>54’48”**</td>
<td>11/11/2016</td>
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<td>Frank</td>
<td>82’17”</td>
<td>10/18/2016</td>
<td>Betty</td>
<td>69’11”</td>
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<td>Steve</td>
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<td>10/20/2016</td>
<td>Paula</td>
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<td>Pam</td>
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<td>10/26/2016</td>
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<td>Kate</td>
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* Phone interview in three parts: 11/02/2016 (18’20”) and 11/09/2016 (21’41” and 15’00”)

** Phone interview in two parts: 11/04/2016 (23’14”) and 11/11/2016 (31’34”)

---

This table provides the dates and lengths of interviews conducted for each participant. The asterisks denote specific interview segments, indicating the phone interviews were conducted in multiple parts as noted in the footnotes.
## Appendix J

### Dates and Times of Participants' Classroom Observations

Table 1

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<th>Time</th>
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<td>Mary 2</td>
<td>01/24/2017</td>
<td>1:10-1:56</td>
<td>Frank 2</td>
<td>11/11/2016</td>
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**TOTAL** 424 minutes

**TOTAL** 770 minutes
Appendix K

Timeline of Research Activities

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Appendix L

MAIT Survey Results

Table 1

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<th>Mode</th>
<th>Percentage</th>
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<td>1. I am aware of the strengths and weaknesses in my teaching.</td>
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<tr>
<td>2. I try to use teaching techniques that worked in the past.</td>
<td>Procedural</td>
<td>4.33 (0.53)</td>
<td>4</td>
<td>86.67%</td>
</tr>
<tr>
<td>3. I use my strengths to compensate for my weaknesses in my teaching.</td>
<td>Conditional</td>
<td>3.94 (0.53)</td>
<td>4</td>
<td>78.89%</td>
</tr>
<tr>
<td>4. I pace myself while I am teaching to have enough time.</td>
<td>Planning</td>
<td>3.86 (0.59)</td>
<td>4</td>
<td>77.22%</td>
</tr>
<tr>
<td>5. I ask myself periodically if I meet my teaching goals while I am teaching.</td>
<td>Monitoring</td>
<td>3.92 (0.69)</td>
<td>4</td>
<td>78.33%</td>
</tr>
<tr>
<td>6. I ask myself how well I have accomplished my teaching goals once I am finished.</td>
<td>Evaluation</td>
<td>4.08 (0.60)</td>
<td>4</td>
<td>81.67%</td>
</tr>
<tr>
<td>7. I know what skills are most important to be a good teacher.</td>
<td>Declarative</td>
<td>3.97 (0.61)</td>
<td>4</td>
<td>79.44%</td>
</tr>
<tr>
<td>8. I have a specific reason for choosing each teaching technique I use in class.</td>
<td>Procedural</td>
<td>3.81 (0.62)</td>
<td>4</td>
<td>76.11%</td>
</tr>
<tr>
<td>9. I can motivate myself to teach when I really need to teach.</td>
<td>Conditional</td>
<td>4.17 (0.61)</td>
<td>4</td>
<td>83.33%</td>
</tr>
<tr>
<td>10. I set my specific teaching goals before I start teaching.</td>
<td>Planning</td>
<td>3.50 (0.94)</td>
<td>4</td>
<td>70.00%</td>
</tr>
<tr>
<td>11. I find myself assessing how useful my teaching techniques are while I am teaching.</td>
<td>Monitoring</td>
<td>4.17 (0.74)</td>
<td>4</td>
<td>83.33%</td>
</tr>
<tr>
<td>12. I ask myself if I could have used different techniques after each teaching experience.</td>
<td>Evaluation</td>
<td>3.97 (0.91)</td>
<td>4</td>
<td>79.44%</td>
</tr>
<tr>
<td>13. I have control over how well I teach.</td>
<td>Declarative</td>
<td>3.94 (0.53)</td>
<td>4</td>
<td>78.89%</td>
</tr>
<tr>
<td>14. I am aware of what teaching techniques I use while I am teaching.</td>
<td>Procedural</td>
<td>3.89 (0.52)</td>
<td>4</td>
<td>77.78%</td>
</tr>
<tr>
<td>15. I use different teaching techniques depending on the situation.</td>
<td>Conditional</td>
<td>4.42 (0.50)</td>
<td>4</td>
<td>88.33%</td>
</tr>
<tr>
<td>16. I ask myself questions about the teaching materials I am going to use.</td>
<td>Planning</td>
<td>4.03 (0.70)</td>
<td>4</td>
<td>80.56%</td>
</tr>
<tr>
<td>17. I check regularly to what extent my students comprehend the topic while I am teaching.</td>
<td>Monitoring</td>
<td>3.94 (0.71)</td>
<td>4</td>
<td>78.89%</td>
</tr>
<tr>
<td>18. After teaching a point, I ask myself if I’d teach it more effectively next time.</td>
<td>Evaluation</td>
<td>4.31 (0.58)</td>
<td>4</td>
<td>86.11%</td>
</tr>
<tr>
<td>19. I know what I am expected to teach.</td>
<td>Declarative</td>
<td>4.17 (0.77)</td>
<td>4</td>
<td>83.33%</td>
</tr>
<tr>
<td>20. I use helpful teaching techniques automatically.</td>
<td>Procedural</td>
<td>3.64 (0.68)</td>
<td>4</td>
<td>72.78%</td>
</tr>
<tr>
<td>21. I know when each teaching technique I use will be most effective.</td>
<td>Conditional</td>
<td>3.17 (0.65)</td>
<td>3</td>
<td>63.33%</td>
</tr>
<tr>
<td>22. I organize my time to best accomplish my teaching goals.</td>
<td>Planning</td>
<td>3.58 (0.55)</td>
<td>4</td>
<td>71.67%</td>
</tr>
<tr>
<td>23. I ask myself questions about how well I am doing while I am teaching.</td>
<td>Monitoring</td>
<td>4.14 (0.54)</td>
<td>4</td>
<td>82.78%</td>
</tr>
<tr>
<td>24. I ask myself if I have considered all possible techniques after teaching a point.</td>
<td>Evaluation</td>
<td>3.42 (0.87)</td>
<td>4</td>
<td>68.33%</td>
</tr>
</tbody>
</table>
Appendix M

Diagnosis of Linear Regression Assumptions

Scatterplot

Dependent Variable: MAIT Av

Regression Standardized Predicted Value

Regression Standardized Residual
Table 2

Co-linearity Test

<table>
<thead>
<tr>
<th>Model</th>
<th>Eigenvalue</th>
<th>Condition Index</th>
<th>(Constant)</th>
<th>EXP (years)</th>
<th>Variance proportions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SCHOOL SES (%FRL)</td>
<td>MAT or UG</td>
<td>Male or female</td>
<td>Group age</td>
<td>No. of courses</td>
</tr>
<tr>
<td>1</td>
<td>5.018</td>
<td>1.000</td>
<td>0.00</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>2</td>
<td>0.850</td>
<td>2.430</td>
<td>0.00</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>0.494</td>
<td>3.186</td>
<td>0.00</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>4</td>
<td>0.266</td>
<td>4.346</td>
<td>0.00</td>
<td>0.25</td>
<td>0.41</td>
</tr>
<tr>
<td>5</td>
<td>0.190</td>
<td>5.140</td>
<td>0.00</td>
<td>0.00</td>
<td>0.25</td>
</tr>
<tr>
<td>6</td>
<td>0.122</td>
<td>6.401</td>
<td>0.00</td>
<td>0.62</td>
<td>0.16</td>
</tr>
<tr>
<td>7</td>
<td>0.060</td>
<td>9.167</td>
<td>0.99</td>
<td>0.09</td>
<td>0.16</td>
</tr>
</tbody>
</table>

Normal P-P Plot of Regression Standardized Residual

Dependent Variable: MAIT Av
Appendix N

Descriptive Statistics of the Sample (MAIT Survey)

Table 1

<table>
<thead>
<tr>
<th>Description</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAIT</td>
<td>3.938</td>
<td>0.282</td>
<td>36</td>
</tr>
<tr>
<td>Experience</td>
<td>2.083</td>
<td>1.296</td>
<td>36</td>
</tr>
<tr>
<td>School SES (%FRL)</td>
<td>41.44%</td>
<td>23.656%</td>
<td>36</td>
</tr>
<tr>
<td>Program (1=MAT; 0=UG)</td>
<td>0.361</td>
<td>0.487</td>
<td>36</td>
</tr>
<tr>
<td>Gender (1=male; 0=female)</td>
<td>0.444</td>
<td>0.504</td>
<td>36</td>
</tr>
<tr>
<td>Group age (0=&lt;25; 1=25-30; 2=&gt;31)</td>
<td>1.028</td>
<td>0.774</td>
<td>36</td>
</tr>
<tr>
<td>Number of courses</td>
<td>1.944</td>
<td>1.013</td>
<td>36</td>
</tr>
</tbody>
</table>
Appendix O

Frequency of Words Used by Teachers to Define Metacognition

Table 1

<table>
<thead>
<tr>
<th>Word</th>
<th>Frequency</th>
<th>%</th>
<th>Rank</th>
<th># of Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>thinking</td>
<td>49</td>
<td>24.5</td>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>how</td>
<td>32</td>
<td>16.0</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>think</td>
<td>31</td>
<td>15.5</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>learning</td>
<td>18</td>
<td>9.0</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>know</td>
<td>17</td>
<td>8.5</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>reflection</td>
<td>17</td>
<td>8.5</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>way</td>
<td>7</td>
<td>3.5</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>looking</td>
<td>5</td>
<td>2.5</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>improve</td>
<td>4</td>
<td>2.0</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>why</td>
<td>4</td>
<td>2.0</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>conclusion</td>
<td>3</td>
<td>1.5</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>evaluate</td>
<td>3</td>
<td>1.5</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>hypothesis</td>
<td>3</td>
<td>1.5</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td>understanding</td>
<td>3</td>
<td>1.5</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>aware</td>
<td>2</td>
<td>1.0</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>conclusions</td>
<td>2</td>
<td>1.0</td>
<td>15</td>
<td>1</td>
</tr>
</tbody>
</table>
Appendix P

Participants’ Understanding of Metacognition, Self-regulation, Nature of Science, and Scientific Thinking

Table 1

<table>
<thead>
<tr>
<th>Part.</th>
<th>Metacognition</th>
<th>Reflection</th>
<th>Self-regulation</th>
<th>Nature of science</th>
<th>Scientific thinking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paula</td>
<td>Never understood it. I don't know.</td>
<td>Encouraging to think about their learning. She does not do it often. Students don't like science. Students don’t care.</td>
<td>Didn’t know. I never understood it. Thinking outside the box.</td>
<td>Thinking as a scientist. Curiosity, asking questions. Using prior knowledge, coming up with questions. Connecting with other content. Observations and asking questions. Inquiry is about projects, labs, hands-on activities. Understand concepts by seeing them, having an experience, applying them in real life. Seeing, touching, feeling what they are studying.</td>
<td></td>
</tr>
<tr>
<td>Elsa</td>
<td>Thinking about learning. Thinking about your feelings. Coming up with a procedure, verifying validity of results, recognizing problems and bias in a scientific paper, being able to solve problems. Recognizing when something went wrong, recognizing problems. Recognizing human error in measurements, asking students questions to lead them to what to think, coming up with conclusions. Unsure.</td>
<td>Asking questions about what they want to change in class.</td>
<td>Monitoring your behaviors and learning, taking ownership of learning. Participating in group work. Working without teachers' supervision.</td>
<td>I don't know how to explain it. Buzzword.</td>
<td>Using the &quot;scientific method,&quot; problem solving, figuring out patterns or trends. Figuring out if information is &quot;scientific.&quot; &quot;Thinking as a scientist.&quot; Inquiry. Teaching the scientific method in an intro unit. Lab activities. At the beginning of the year, asking them to solve a problem.</td>
</tr>
<tr>
<td>Frank</td>
<td>Thinking about thinking. Thinking about learning. Reflecting in your development. Thinking about learning and using it for teaching. It is about thinking. Metacognition is not a comfortable word. Prefer using the word &quot;reflection&quot; with students.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td>---------------------------------------------------------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>How science is and is done. Science as setting up an experiment and proving a hypothesis. You can use NOS without being aware of it. Analyzing data to improve performance or make predictions. Having procedures for how to do thinking (first observations, second, testing, etc.). Scientific process is simplified and inaccurate. Trying to find answers after observations. Setting an experiment. Reaching conclusions. Not heard the term &quot;scientific thinking.&quot; He teaches the engineering process, which &quot;is akin to the scientific process.&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Figuring out steps to solve a problem. Explaining why. Scientific thinking. Critical thinking. Solving problems. Observing, hypothesis, coming up with a way to solve the problem. Trial and error process. In the standards. Call it scientific method. Teach it at the beginning of the year and then do experiments throughout the year. Critical thinking is having steps, a way to solve a problem. No right or wrong answers. Doing labs, making predictions.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lucy</td>
<td>Thinking about learning. Thinking about thinking. Reflection. She doesn't explicitly ask students to use metacognition, but she knows that's what she is doing.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thinking about learning. Stop actions and think. Coming up with more questions. Thinking after learning.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Knowing how science works and how knowledge evolves over time. Communicating science. Knowing influences in the scientific process like society, time, and culture. Understanding how knowledge changes and evolves. The process scientists use, the scientific method. Thinking as a non-linear process. Different ways of knowing.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>“Thinking like a scientist.” “Mimic in class what scientists do.”</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pam</th>
<th>Thinking about thinking. Identifying how you think, or learning style. Thinking about why or about your reasoning Thinking about how came up with an answer.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reflection on learning. Asking how do you feel. Finding applications to the content.</td>
</tr>
<tr>
<td></td>
<td>Taking responsibility for your thinking and learning.</td>
</tr>
<tr>
<td></td>
<td>Scientific thinking. How ideas and hypotheses come up. Questioning, testing, and concluding. Science not in the classroom but embedded in real life. We are naturally curious. Talking about science and how it is related with everyday life. Talking about history of science, the people involved. Human things that happened in scientific discoveries. Giving the students fun facts about science and talking about them. Giving students tips. Talking about history.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Steve</th>
<th>Reflecting on your thinking. Improving teaching. Improving as students. Improving their understanding of science.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Better word. Go hand in hand. Looking back at yourself. Understanding what you're doing. Improving. Students don't have a pause point to reflect about what is appropriate in a classroom. Students react without thinking. Students do not connect their behaviors or performances with their grades. Help students to develop accountability because they don't have it.</td>
</tr>
<tr>
<td></td>
<td>Being able to control your thoughts, emotions, and actions. Goes hand in hand with reflection. Participating in a group.</td>
</tr>
<tr>
<td></td>
<td>Going over it at the beginning of the semester. Talking about the scientific method, the scientific process. Steps to solve problems or answer questions. How the method of science reaches conclusions. At the beginning of the school year and reinforce it throughout the year. Critical thinking questions. Writing prompts. Answering questions.</td>
</tr>
<tr>
<td>Henry</td>
<td>Thinking about thinking. How you draw conclusions. Thought process when designing a lesson. Thinking about goals. Reflecting or being aware of learning, and the steps made when answering a problem. Answering questions like how or why after doing something. A big step. It is a higher level. The next step. Being okay with mistakes, thinking about what went wrong after an experiment. Making a diagnosis of a problem. Making connections with other subjects. Learning how to learn. Thinking on thought process, when students are struggling. Identifying a problem, figuring out how to test a hypothesis, testing one variable at the time, rethinking how you came up with an experiment. Applying concepts. Unsure. Being independent learners. Thinking why, reasons for their answers.</td>
</tr>
<tr>
<td>-------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>Thinking about actions. Thinking about how relevant the information is.</td>
</tr>
<tr>
<td></td>
<td>Controlling yourself. Thinking on the consequences of your actions. Requires maturation.</td>
</tr>
<tr>
<td></td>
<td>Studied during his Master’s program, a professor modeled it. A new way of thinking about science and phenomena. A fascinating idea. “Mystic.” You can do research without thinking about it. Science as a discipline, a human endeavor. Science as a &quot;faulty, messy,&quot; human way to get knowledge. But, the “best way” we have. Science as a &quot;touchable,&quot; &quot;idealistic thing.&quot; Science is a process. Start from knowing something to knowing something.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific method. The steps of the scientific method.</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>Emma</td>
</tr>
<tr>
<td>Betty</td>
</tr>
<tr>
<td>Jean</td>
</tr>
</tbody>
</table>
Appendix Q

Table 1

Participants’ Ideas of Metacognition, Reflection, and Self-regulation

<table>
<thead>
<tr>
<th>Metacognition</th>
<th>Reflection</th>
<th>Self-regulation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thinking about thinking (12)</strong></td>
<td>Thinking about actions (8)</td>
<td>Self-control (5)</td>
</tr>
<tr>
<td><strong>Thinking as scientists (11)</strong></td>
<td>Trying to bring past, present, and future together. Stop actions and think. Thinking after a learning activity. Understanding what they are doing (2)</td>
<td>Controlling yourself. Checking what you’re doing. Being able to control thoughts, emotions, and actions. Staying on task</td>
</tr>
<tr>
<td>Recognizing problems (4), coming up with hypotheses (3), reflecting on hypotheses (3), coming up with experiment (3), testing one variable, making predictions, verifying validity of results, identifying bias (2), answering why (4), coming up with conclusions (3), thinking about how you draw conclusions (5), understanding of science</td>
<td><strong>Thinking about learning. (7)</strong></td>
<td>Taking ownership for learning (4)</td>
</tr>
<tr>
<td>Reflecting (10) Development, learning, self-reflecting, thinking, after labs or a topic</td>
<td><strong>Thinking about feelings (3)</strong></td>
<td>Working independently (4)</td>
</tr>
<tr>
<td><strong>Thinking about learning (10)</strong> Using it for teaching (2); independent learners (2), learning style, lifelong learners</td>
<td>Assessing (5) Formative assessment, learning (2), improving (2)</td>
<td>Monitoring learning (3) Monitoring your behaviors and learning. Self-motivation for learning</td>
</tr>
<tr>
<td><strong>Thinking (8)</strong> About actions (2), goals (2), reasoning, thought process, analyzing thinking (2)</td>
<td><strong>Quiet or individual time (3)</strong> Looking back at yourself</td>
<td>Knowing yourself (3) Identifying limitations. Identifying when help is needed</td>
</tr>
<tr>
<td><strong>Don’t know or unsure (7)</strong></td>
<td>Related with metacognition (3)</td>
<td>Participating in a group without teachers’ supervision (2)</td>
</tr>
<tr>
<td><strong>Self-evaluation (6)</strong> Improving (3), self-evaluating (2), peer-evaluating, do and don’t know, does and doesn’t work (2), need to change</td>
<td>Asking questions about what students want to change in class</td>
<td>Working on behavior (2) Awareness of behavior and actions that do or do not promote learning</td>
</tr>
<tr>
<td><strong>Getting one step further (6)</strong> Deeper reflection, documenting and revisiting, higher level, double cycle, all senses, re-thinking, re-evaluating</td>
<td>Regular practice</td>
<td>Do not know (2) Not heard in educational settings</td>
</tr>
<tr>
<td><strong>Thinking about what went well or wrong (5)</strong> after a labs or problems</td>
<td>Writing or changing conclusions. Coming up with more questions</td>
<td><strong>Thinking about thinking</strong> Synonym of metacognition and reflection</td>
</tr>
<tr>
<td><strong>Making connections (3)</strong> Other subjects, prior knowledge, past experiences or big ideas, applying concepts</td>
<td>Finding applications for the content</td>
<td>Thinking about the consequences of your actions</td>
</tr>
<tr>
<td>Being aware (3), thinking about feelings (2).</td>
<td>Thinking about how relevant the information is</td>
<td>Requires maturation</td>
</tr>
</tbody>
</table>
Appendix R

Metacognitive Teaching Practices, Factors Facilitating and Limiting Metacognition

Table 1

<table>
<thead>
<tr>
<th>How participants use metacognitive or reflective teaching</th>
<th>What helps metacognitive or reflective teaching</th>
<th>Limitations on metacognitive or reflective teaching</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Paula</strong></td>
<td>Didn’t understand metacognition. (R) Exit summaries, application questions in worksheets. Writing conclusions in a lab report about learning and purposes of the activity.</td>
<td>Standards. Learned in TEP. It is good for the students to see what they are learning, the purpose of what they are doing. Helps students to see the purpose of labs. Helps students to see the purpose of what they are doing in school.</td>
</tr>
<tr>
<td><strong>Elsa</strong></td>
<td>Recognizing whether numbers make sense, recognizing experimental error, not giving them the answers but asking them to find out their mistakes. Lab notebooks. Verbal questioning, talking to them about human error, giving them a check list of possible problems in an experiment. Openers (bell ringers) about learning, how they feel. Self-assessment with a rubric, write about their process for parent conferences. Giving students prompts to reflect about the class.</td>
<td>Practice. Make students accountable for their results and what they should do for next time. The teacher saw changes in her students. When it is not judgmental. Students can realize what they need to do to have a better performance in class. Learned in TEP.</td>
</tr>
<tr>
<td><strong>Frank</strong></td>
<td>Evaluating their skills. Improving a project. Practicing it in class. Having a real problem to improve. Assessing performance of skills using a rubric. At the end of projects. Asking students to reflect verbally about their actions during class.</td>
<td>Recognizing the role of reflection in sharing learning responsibility with students and developing skills. Using it in the real word to solve real problems. Improving a product. Students do it informally without noticing it. Reflection is a common term. Using it because it is part of the curriculum.</td>
</tr>
<tr>
<td><strong>Gina</strong></td>
<td>Students thinking about why they are doing something. Evaluating group projects. Exit tickets. Prompts to analyze performance after an assessment (e.g., quiz). Analyzing how they studied for a quiz, how to improve their</td>
<td>Recognizing its importance for learning. Easy for advanced students or students who care about their grades and are open to a growth mindset. Easy for students with supportive parents. Learned in TEP.</td>
</tr>
<tr>
<td>Name</td>
<td>Action</td>
<td>Consideration</td>
</tr>
<tr>
<td>-----------</td>
<td>------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Kate</td>
<td>Considered important for making students responsible for their learning.</td>
<td>Not using it frequently. Focusing on content. Need more teaching experience to teach it. Adding those pieces later. It is a bigger piece. She needs to feel comfortable with teaching first. Difficult for students with a different mindset. Some students do not care about it. Student have bad attitudes about reflection. Students with a lack of parental support don't care about learning. Students need to be accustomed to thinking like that. Students have been ultra-regulated in school. Limited teaching experience.</td>
</tr>
<tr>
<td>Steve</td>
<td>Set up goals at the beginning of the year. He hears it in his school. Standards. Learned in TEP.</td>
<td>New teacher, he is still &quot;learning and running.&quot; It is hard for students to be accountable for their grades and actions. Don't know how to do it.</td>
</tr>
<tr>
<td>Pam</td>
<td>Having it in the standards. Used in other training outside TEP. Believe that students will learn better. It is helpful for students' learning. Some students are good at it. Learned in TEP. Talking about science in different contexts outside the classroom.</td>
<td>Not sure how to do it. It is a new skill for some students. They don't practice it and do not know how to do it. Students struggle thinking in a new way. Not used to applying it in classroom settings. Some students are better than others. Students programmed to say the right answer. Students consider it not useful. Students tend to think &quot;inside the box.&quot;</td>
</tr>
<tr>
<td>Lucy</td>
<td>Teaching experience. Knowing the curriculum better. Having it in the standards.</td>
<td>More focused on the content. She needs more experience. Students don't enjoy writing conclusions or reflecting. Time. She must move on</td>
</tr>
<tr>
<td>Steve</td>
<td>Having it in the standards. Used in other training outside TEP. Believe that students will learn better. It is helpful for students' learning. Some students are good at it. Learned in TEP. Talking about science in different contexts outside the classroom.</td>
<td>Not sure how to do it. It is a new skill for some students. They don't practice it and do not know how to do it. Students struggle thinking in a new way. Not used to applying it in classroom settings. Some students are better than others. Students programmed to say the right answer. Students consider it not useful. Students tend to think &quot;inside the box.&quot;</td>
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<tr>
<td>Kim</td>
<td>Having it in the standards. Used in other training outside TEP. Believe that students will learn better. It is helpful for students' learning. Some students are good at it. Learned in TEP. Talking about science in different contexts outside the classroom.</td>
<td>Not sure how to do it. It is a new skill for some students. They don't practice it and do not know how to do it. Students struggle thinking in a new way. Not used to applying it in classroom settings. Some students are better than others. Students programmed to say the right answer. Students consider it not useful. Students tend to think &quot;inside the box.&quot;</td>
</tr>
<tr>
<td><strong>Thinking about how to improve their grades, what support they need from the teacher. Reflecting about behaviors in class. One-on-one reflection about behaviors.</strong> Questioning one-on-one. (R) In the back of the classroom, talking and asking questions to students with goofy behaviors in class. Reflecting on their grades. Students do it independently. Handing back tests for students to think about their learning. (NOS) Encouraging students’ curiosity, questions, and scientific thinking. Discussing the NOS.</td>
<td><strong>Some students are good, some are not. He does not hear those words often.</strong></td>
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<tr>
<td><strong>Henry</strong> Questioning techniques, after projects, when solving problems, about their learning, how do they feel. Unsure. Reminding students to study or how to study. Using the same procedures and instructions to solve problems so students learn how to use them. Giving reasons for their answers when solving a problem, after a lab or a demo, for predictions, learning from their mistakes. Showing their work in a problem, to redo tests.</td>
<td><strong>Learned in TEP.</strong> Write down what students think.</td>
<td><strong>Students don’t want to think. It will come with time. Students are not motivated to collaborate. Their attention is short. There is not enough time. Finding ways.</strong></td>
</tr>
<tr>
<td><strong>David</strong> Good for students assessing their performance after a test. Explaining instructional decisions in class. Explaining why they are studying a certain topic or the rationale for the teacher’s actions. Evaluating students’ performance before or after an assessment. Students thinking about learning objectives to assess if they are ready for a test.</td>
<td>Thinking about the epistemology of science can change the way of thinking. The NOS is fascinating. Learned in the TEP. He likes the topic (NOS). Professor modeling that way of thinking (NOS).</td>
<td><strong>Never heard the world “metacognition” at school. Don’t believe he can make students think about something. No time for doing reflection. No time for that in class. Students should do it mentally. There is no way to know what the students are doing. It is hard to make students understand the NOS. Students need to be cognitively “ready” to understand NOS. Teaching NOS can lead to oversimplifications of science. Lying when teaching about science as a method. It is a process. A way of knowing. Other teachers disregard these ideas.</strong></td>
</tr>
<tr>
<td><strong>Emma</strong> To question society or themselves; Writing about their thinking or how they concluded something after a lab. Getting the students comfortable thinking about their thoughts. Giving the students prompts or questions. Evaluating a conclusion. Sitting and analyzing their thoughts. Using scientific practices (thinking about data, coming up with conclusions, analyzing results, finding trends, comparing predictions and conclusions) after activities. Formative assessment: exit tickets.</td>
<td>Learned how to do it in MAS. Modeled by professors in her TEP. Learned in TEP. Learned in UG. Flexibility in the curriculum. Recognizing the importance of reflection.</td>
<td><strong>Never used reflection about NOS as an UG. NOS is too broad. Never heard them in school. Students never heard about it. She doesn’t know exactly how to use it. Teachers need to keep a fun classroom. Reflection is quiet and shields students away. Students need to be calm and relaxed to do it. Students prefer to be active. It is boring. It can be uncomfortable. Easy to get distracted.</strong></td>
</tr>
<tr>
<td>Betty</td>
<td>Writing goals and checking them after vocab quiz. Showing their work in a problem. Being aware of what they did wrong, reflecting on their performance. Asking students questions about what they did wrong. Talking to them about what went wrong. I don’t know. “Forcing” students to care about their grades. Writing a list of things they understand and things they don’t understand. Sending an email with a few paragraphs about their learning. Asking them to look at their grades after a test. Asking students to write full sentences, telling students what you want. Questions.</td>
<td>Control over what she teaches because she is the only one teaching it. Flexibility. When kids care. For those who do not care, you need to &quot;force&quot; them to care. Writing about learning in an email, typing instead of handwriting. Knowing that the teacher will follow up on reflections. Having to turn in their written reflections. Giving students questions. Having concrete criteria for what they need to do. She teaches a new class. It is about problem solving. It is new for her and she follows what other teachers ask her to do. It is hard. Some students never get it.</td>
</tr>
<tr>
<td>Jean</td>
<td>(NOS) Teaching the history of scientific theories and scientists. Reading articles and relating the subject with the current world. Giving students websites with information that could be relevant for their lives. Helping students make connections. Analyzing pictures and coming up with answers.</td>
<td>Learned in TEP. Having them in common assessments and standards. Mentioned in some PD but not in depth. Not heard in her school. Trying to make them think. Students don't want to reflect. They give short answers. They get tired. It is hard. Students don't like it. Students refuse to think. Students have been &quot;spoon-fed.&quot; It is hard for them to think for themselves.</td>
</tr>
<tr>
<td>Matt</td>
<td>(MG) Goals before testing. Reflecting about what went well and wrong. I don't do it in my classroom. (R) Discussing with students after assessments. Questioning about participation in lab activities. Questioning about tests, how to help them in their learning or their progress. Formative assessment, writing how they feel on a chart, how they rate themselves. Writing down things after questions about teamwork or lab activities. (NOS) Talking about the difference between science and technology. Incorporating NOS all the time.</td>
<td>Flexibility. Ownership of what he does in the classroom. Support from his administrator to implement new things. Can help students focus, become more accountable for their learning. It is important. Learned in TEP. He thinks it can help students. His experience working as a scientist. He does not know. It is hard. Students don’t make connections that you think are obvious. Must do “other stuff.”</td>
</tr>
<tr>
<td>Mary</td>
<td>Writing about what they learned after a lecture or a lab. Giving students writing prompts. Asking students to write full sentences. Using reflections as part of the grading.</td>
<td>Flexibility to order objectives and curriculum. Practice. Writing prompts and using them frequently. It is a good synopsis of learning that helps students and teachers. Students feel disdain for it. They don't like it because it's hard. It is thinking in a different way. Boys have more difficulties writing about their thinking. Used in the TEP but she cannot remember for sure. Reflections take time. It is not easy.</td>
</tr>
<tr>
<td>Giving some criteria for their reflections, e.g., two complete sentences. Asking students to write questions they want to answer about the topic. Summarizing their learning. Putting it in their own words. Thinking about what they would like to know about that topic. At the end of a lesson.</td>
<td>Good to differentiate learning, gives higher achievers opportunity to extend learning. Giving writing prompts at the beginning of the school year. Took a class during her UG where the professor did it. Learned in TEP. Seen in the standards.</td>
<td></td>
</tr>
</tbody>
</table>
Appendix S

Mary’s Rubric for Reflective Questions

![Rubric Image]

**Figure 4.8.** Rubric and criteria to assess reflections from 6th grade students
**Appendix T**

Frank’s Rubrics and Description of Project

Table 1

*Rubric with Evaluation Criteria. In Bold are the Reflective Pieces*

<table>
<thead>
<tr>
<th>Location</th>
<th>Criteria</th>
<th>Description</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineer’s notebook</td>
<td>Organization</td>
<td>Subtitles are used to guide the report (i.e., criteria subtitles are evident, report follows the order in this rubric).</td>
<td>__/15</td>
</tr>
</tbody>
</table>
|                           | Define the problem | **Goal of project defined.**  
                           |                                                | **Team norms are clearly written (at least three norms)** | __/5   |
|                           | Generate Concepts  | Sketches are included (one per team member).  
                           |                                                | Pseudocodes based upon sketches are included (one per team member). | __/5   |
|                           |                    | **Decision Matrix is completed.**  
                           |                                                | Design brief includes the justification for the project. | __/5   |
|                           |                    | Design brief includes the expected materials (cost) | __/5   |
|                           | Develop a solution | Pictures of the building process are included.  
                           |                                                | Descriptions of the building process pictures are included. | __/5   |
|                           | Construct a test and prototype | Final product picture(s) included. | __/5   |
|                           |                    | Final RobotC codes included. | __/5   |
|                           |                    | Final RobotC Code includes task description and pseudocode. | __/5   |
|                           |                    | Final RobotC Code includes comments. | __/5   |
|                           | Evaluate a solution | **Robot is evaluated:**  
                           |                                                | 1. What was one challenge you faced, how did you overcome it? | __/5  |
|                           |                    | 2. How effective was your robot (i.e., how often does it perform accurately)? | __/5   |
|                           |                    | 3. What are the limitations of your robot? | __/5   |
|                           |                    | 4. Robot cost (amount of materials) is included. | __/5   |
|                           |                    | 5. What would you change about your final design to make it better? | __/5   |
| Expo presentation         | Present the solution | Presentation follows the 10-20-30 rule. | __/5  |
|                           |                    | Presentation is pointed towards the specified audience. | __/5  |
|                           |                    | Expo is attended and professional. | __/10  |
|                           |                    | Expo reflection is complete and thorough. | __/15  |
| Evaluation forms          | Team evaluation    | **Average of team evaluation forms.** | __/10  |
| Engineer’s notebook check | Notebook check     | Final Engineer’s Notebook check. | __/50  |
|                           | TOTAL              |                                                             | __/200  |
**Rubric for Team Evaluation.**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Description</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participation</td>
<td>The team member was an active participant within our group.</td>
<td>__/2</td>
</tr>
<tr>
<td>Time management</td>
<td>The team member was on task during the project.</td>
<td>__/2</td>
</tr>
<tr>
<td>Fairness</td>
<td>The team member was kind and fair to other members in the group.</td>
<td>__/2</td>
</tr>
<tr>
<td>Responsibility</td>
<td>The team member faithfully fulfilled their responsibilities to the group, particularly those outlined in the group norms.</td>
<td>__/2</td>
</tr>
<tr>
<td>Communication</td>
<td>The team member effectively communicated with other members.</td>
<td>__/2</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td>__/10</td>
</tr>
</tbody>
</table>