EXPLORING PRESERVICE TEACHERS' DEVELOPMENT OF AWARENESS OF STUDENT THINKING

by

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ABSTRACT OF THE DISSERTATION

Exploring preservice teachers development of awareness

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Numerous reports have emphasized the need to engage students with the practices of scientific inquiry, specifically model-based inquiry in which students develop models to explain phenomena. A key factor in implementing this practice is the ability for teachers to attend and interpret student learning to guide instructional design. Research shows that experienced teachers' understanding of learners influences their instructional design; however the research on preservice teachers (PT) has mixed results. For example, several studies have reported that PTs foresee few student learning difficulties when planning lessons while other studies found that PTs do acknowledge the importance of student ideas. Further, even when PTs do acknowledge student thinking, they are not clear what to do to ameliorate these misunderstandings. Being able to attend and respond to student thinking is based on the construct of noticing, which is the ability to notice and interpret significant interactions in the classroom. Due to the complex and dynamic nature of the classroom, it is difficult for PTs to develop these skills in real time due to the logistics involved in obtaining videos of PT instruction and the cognitive load involved in attending to the messy contexts of the real classroom environment. To circumvent this problem, teacher educators can focus on the precursors of noticing including framing and developing an awareness of student thinking; therefore, this

dissertation focuses on the development of these precursors. The findings from these three studies will provide teacher education researchers with a clearer picture of where PTs are still struggling in their development; thus, they will be able to design and implement appropriate interventions that can help enhance these practices.

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1.1. Statement of the Problem

Standards documents and policy reports have emphasized the importance to engage students with the epistemology and practices of scientific inquiry (National Research Council [NRC], 1996, 2007, 2011). Engagement in these practices consequently involves a shift towards more student-centered classrooms in which students construct their own understandings of scientific phenomena (NRC, 2000; 2007). Teachers facilitate students' science learning, thus, it is imperative that teachers develop the knowledge, beliefs, and practices to implement inquiry teaching (Abd-El-Khalick, Bell & Lederman, 1998; Abd-El-Khalick & Lederman, 2000; Nott & Wellington, 1996). However, this can be challenging because many teachers have not had much experience with authentic scientific inquiry practices either in their own education or in their teacher preparation (Crawford & Cullin, 2004; Harrison, 2001; Justi & van Driel, 2005; Justi & Gilbert, 2002; Windschitl & Thompson, 2006). In general, teachers have trouble interpreting student ideas and using their interpretations to guide instructional design.

A key factor in implementing inquiry-based teaching is the ability to attend to and interpret student ideas and to use such interpretations to guide instructional design (Hammer, 2000; van Zee & Minstrell, 1997; NRC, 1996; AAAS, 1993). The ability to interpret events in a given domain is what Goodwin (1994) termed professional vision. For example, a detective's professional vision allows him to make sense of a crime scene. van Es and Sherin (2002) developed the framework of "noticing" based on Goodwin's notion of professional vision. The construct of noticing involves teachers being able to attend to student ideas, interpret how those ideas relate to the overall learning process, and implement appropriate instructional strategies to help ameliorate any misunderstandings. However, developing these skills can be challenging since their application happens in a manner that is fleeting and that is distributed through the moments of instruction (Sherin et al., 2008). This fleeting, complex, and dynamic nature of noticing poses challenges for teacher educators. It is often difficult to help preservice teachers (PTs) notice in real time due to the cognitive load involved in attending to the messy contexts of real classroom interactions as well as the logistics involved in obtaining videos of PTs instruction. To circumvent this problem, teacher educators can focus on the development of potential precursors to noticing. I present three constructs that I propose can serve as precursors (figure 1.1): (a) framing, (b) interpretation of student work, and (c) planned hypothetical responses. I used the phrase *developing an awareness of student thinking*, to denote PTs' ability to: (a) notice evidence of student thinking (in written artifacts); (b) interpret this evidence in terms of how it connects to learning; and (c) decide how to hypothetically respond to their interpretation of students' understanding. I have identified these as precursors to noticing since they do not occur in the moments of instruction but rather occur either after the lesson has been taught or in the evaluation of static student artifacts.

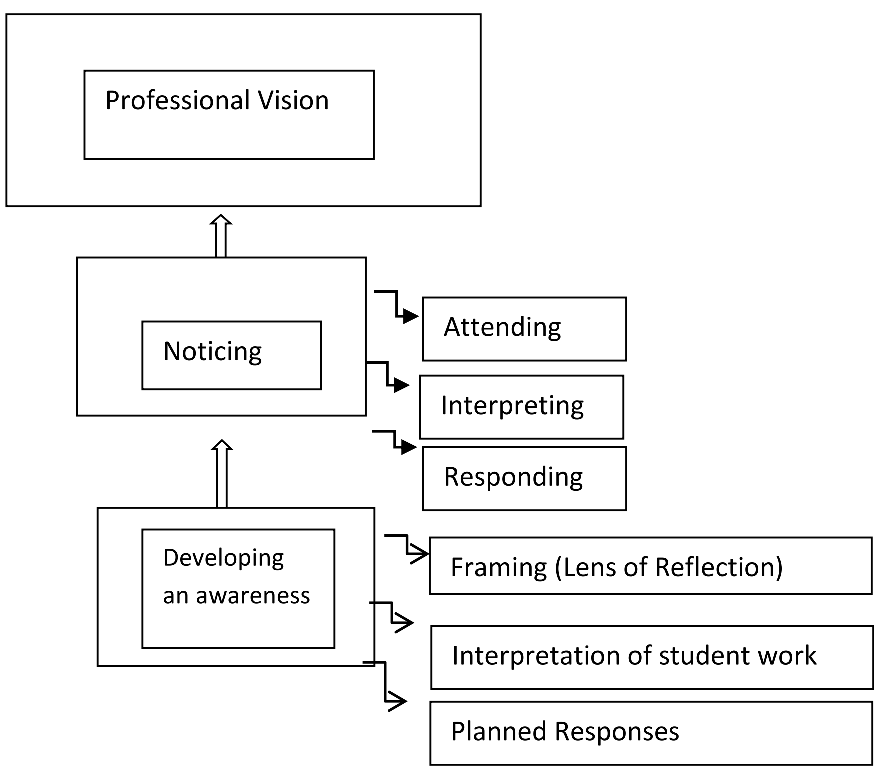


Figure 1.1: Hierarchical order of developing an awareness of student thinking

In this dissertation, I explored how the precursors to noticing, which I termed *developing an awareness of student thinking*, changed over the course of a teacher education program. I investigated the precursors to the construct of noticing since previous research has already indicated that PTs do not interpret student ideas (Morris, 2006) as well as they do not know what to do with the students ideas once they have been surfaced (Davis, 2006). Additionally, since the study of these precursors did not occur in a real classroom environment, it eliminated the complex and dynamic nature of instruction; thus, elimination of these pressures allowed me to ascertain how (if at all) PTs could attend to student understanding. The findings from these studies can shed light on whether or not PTs are able to attend and interpret student thinking when outside pressures have been eliminated. The next section of this introduction will highlight the construct of noticing as well as explore how this construct has been studied in previous research.

1.1.1. Noticing and its application

Part of expertise is having a professional vision (Goodwin, 1994). Teachers also have professional vision, and van Es and Sherin developed the framework of noticing to capture this idea of professional vision for teaching. Understanding how this develops and how teacher educators can support its development can help PTs to become more cognizant of student ideas in their classroom. The construct of noticing consists of three professional skills: (a) identifying what is important, (b) making connections between the specifics of classroom interactions, and (c) using what one knows about the context to reason about the classroom situation.

The first aspect of noticing, identifying what is important in a teaching situation, refers to the ability of the teacher to select what they will attend and respond to in the class. At any given time in a classroom there are many different things going on, thus, the teacher must determine what is important and use this information to guide instruction. The second aspect of noticing, making connections between specific events and broader principles for teaching and learning, refers to the teacher's ability to determine how events in the classroom are connected to student understanding (van Es & Sherin, 2002). Thereby, teachers must be able to interpret how student ideas relate to the students' overall learning process. Finally, the third component of noticing, using what one knows about the context to reason about the situation, refers to teachers noticing classroom interactions (e.g., student ideas) and how they are tied to the specific context one teaches. In other words, teachers must use their knowledge of the subject matter and knowledge of how students think of that subject matter to reason about events as they unfold (van Es & Sherin, 2002). For example, teachers of science will more accurately reason about classroom interactions in a science classroom than interactions in a literature or mathematics classroom. Similarly, chemistry teachers are more facile at interpreting students' understanding of chemical reactions than are biology teachers (van Es & Sherin, 2002).

van Es and Sherin (2002) studied the construct of noticing using a software tool called VAST (video analysis support tools). They attempted to support preservice mathematics teachers in developing the ability to notice and interpret aspects of classroom practice. The PTs analyzed videos of mathematics lessons in terms of student thinking, teacher's roles, and discourse. The VAST software prompted the PTs to: (a) identify what they noticed in the lesson; (b) provide evidence for what they noticed; and (c) provide an interpretation of what they noticed. van Es and Sherin used a four tier coding scheme to analyze PTs comments that captured movement from descriptive to interpretive comments. Descriptive comments included recounting chronological events that occurred in the lesson while interpretive comments involved calling out an event from the videotaped lesson, supporting the “call out” with specific evidence from the video, and interpreting this event in relation to the bigger picture. The authors found that the PTs who used the VAST software were able to shift from descriptive to a more interpretive stance in their analyses of the video.

Although van Es and Sherin used video when studying noticing, others such as Jacobs, Lamb, and Philips (2010) used written work when studying this construct. In their study, Jacobs et al. (2010) used the framework of noticing to uncover how teachers with varying degrees of expertise: (a) attended to children’s mathematical strategies, (b) interpreted children’s mathematical understanding, and (c) decided how to respond to their analyses after participating in continuous professional development (PD) workshops. They found that teachers with more experience were inclined to attend to children’s strategies and interpret children’s understanding; however, regardless of the level of expertise, teachers had difficulty deciding how to respond. That is, even after the teachers identified what students did not understand, they still struggled with suggesting mathematical problems to ameliorate these misunderstandings. Since the teachers were analyzing written work, some aspects of this study are very relevant to the *developing an awareness* construct because similar to the studies conducted in this dissertation; this study did not use real time data.

Other researchers such as Kazemi and Franke (2004) also saw the benefit of using student work. In their study, the authors investigated whether analysis of student work could help teachers develop a deeper understanding and interpretation of their own students' mathematical thinking through collective engagement with other teachers. In this investigation, ten teachers met once a month throughout the course of the school year. At each meeting, teachers selected pieces of student work to share, and the group of teachers described in depth the strategies the students used to solve the mathematical problems. Kazemi and Franke found that when teachers analyzed their students' work they developed more detailed knowledge of their own students' mathematical thinking and began to shape a particular stance about the role of the teacher, namely: (a) teacher's work involves attending to children's thinking; (b) teachers make public their efforts to elicit student thinking; and (c) teachers recognize student's mathematical competencies.

Thus far, I have described the construct of noticing and the various ways that it has been studied. In the investigations conducted as part of my dissertation, I chose to explore the precursors of noticing, *developing an awareness of student thinking*, by evaluating PTs' analyses of static student artifacts. Although engaging PTs in evaluating student artifacts for student thinking does not occur in a real time classroom environment, it is still a very authentic teaching practice. The next section of this introduction will describe the first construct of developing an awareness, *framing*. In order to develop the practices of noticing, PTs must first view the classroom in a way that is cognizant of the learner, i.e., they need to frame classroom teaching as being about student thinking.

1.1.2 Framing

Framing denotes a cognitive lens (or schemas) a teacher uses to make sense of what is going on in the classroom (Levin, Hammer, Coffey, 2009). The framing construct has initially been used in research on physics education, which has shown how student reasoning can settle into different patterns of behavior and interpretations in different situations (Reddish, 2004; Rosenberg, Hammer, & Phelan, 2006). For example, when presented with a physics problem one student may frame the problem to be quantitative, thereby, solving for unknown variables in an algebraic equation. Conversely, another student frames the problem as an occasion for intuitive sense making, thereby, constructing a narrative of the mechanisms noted in the problem.

However, more recently, this construct of framing has been used in teacher education to describe the different ways in which teachers view classroom events. With this view, whether and how teachers attend and respond to student thinking largely reflects how they framed what was taking place in their class. Levin, Hammer, and Coffey (2009) were interested in uncovering whether PTs actually can frame classroom events in ways that highlight student thinking. The authors conducted this investigation because prior research suggested that PTs do not attend to student thinking (e.g., Davis et al, 2006; Friedrichsen et al., 2009). Levin et al. (2009) analyzed field notes, video recordings of lessons, and papers written throughout the course from four PTs enrolled in a teacher preparation program. Their analyses focused on whether and how four PTs' attended to student thinking by how they framed what was taking place in the lesson. Levin et al., (2009) considered evidence of attending to student ideas when PTs noticed and responded to student ideas in their lessons as well as when PTs made claims about student reasoning that was supported with evidence from the data. The authors found that the four PTs in their study used frames that afforded attending to student learning. For example, one PT was aware of student ideas as evidenced by the kinds of questions she asked and the ways she asked the students to elaborate and explain their comments. In this case, the PT attended to student learning by addressing the student responses. Another PT attended to student thinking as evidenced by asking a student to explain her idea and then used that idea as the focus of the subsequent class discussion. The authors argued that the evidence from the case studies noted above suggests that novice teachers have the ability to attend to student thinking, but what they notice in class depends in part on how they frame what they interpreted in the lesson. Thus, when PTs are asked to pay attention to curricular objectives, standards, and their own behaviors than it is not surprising that they do not pay attention to student reasoning. However, when asked to attend to student thinking and student ideas, the PTs are able to. Levin et al. (2009) concluded that while PTs are able to use frames that account for student understanding, teacher education programs must prioritize engagement in this practice before PTs develop routines that distract from student thinking.

In summary, this introduction highlights research that has used the construct of noticing as well as studies that have promoted the practices of noticing in teacher education programs. As evidenced from the studies, developing the skills necessary for noticing is not a trivial task and it is often difficult to train PTs in real time environments; thereby, using artifacts such as written work can be beneficial with developing these skills (e.g., Jacobs et al. (2010); Kazemi & Franke 2004). In the investigations conducted as part of my dissertation, I explored the precursors to noticing, which I termed *developing an awareness of student thinking.* In the first precursor, *framing,* PTs must first view the classroom in a way that is cognizant of learners and their ideas. In the next section of this introduction, I will focus on the importance of reflection and its role in studying the development of awareness of student thinking- specifically attending to student ideas. I will be discussing reflection because as part of this dissertation I used reflection artifacts, like reflection papers, as a means to capture the practices of noticing.

1.1.3 Role of reflection in developing an awareness of student thinking

The ability to reflect critically on one's classroom practice is generally regarded as an essential part of any teachers' professional growth (Jaworski, 2006) and is especially important for beginning teachers (Artzt, 1999; Dinkelman, 2000; Kaminski, 2003). However, PTs often either do not reflect on their practice (Alger, 2006; Shoffner, 2008) or do so in a superficial way (Bean & Stevens, 2002; Collier, 1999). They focus on the technical skills of teaching (Le Cornu & Ewing, 2008) and practical concerns, such as planning and classroom management (Moore, 2003; Nyaumwe, 2004). Several researchers (e.g., Cavanaugh & Prescott, 2010; Colton & Sparks-Langer, 1993; Hatton & Smith, 1995) have advocated for the use of reflection in teacher education programs as a vehicle to shift PTs attention away from themselves and their technical skills and towards attending to student thinking. Further, reflection fosters personal and professional growth, which has been shown to improve teachers' knowledge and awareness of their classroom practices, including developing an awareness of student ideas (Baird, Fensham, Gunstone, & White, 1991).

Reflective practices take on many forms. Valli (1997) argued that there are five types of reflective practices: (a) *technical reflection* occurs when teachers judge general teaching behavior skills like time one task, wait time, and student engagement; (b) *reflection-on-action* occurs after teaching the lesson and focuses on the teacher's values, beliefs, classroom context, and students; (c) *deliberative reflection* occurs when teachers decisions are based on a variety of sources including research, experience, and the advice of other teachers; (d) *personalistic reflection* occurs when teachers link their personal and professional lives by reflecting on what type of person they want to be and how being a teacher helps accomplish that goal; and (e) *critical reflection* occurs when teachers view the school and school knowledge as political constructions and specifically focus on improving the life of disadvantaged groups. The types of reflection noted by Valli (1997) have been studied in both in-service and preservice contexts. Engaging in these types of reflective practices promotes a thoughtful contextualized view of teaching, that is thinking about teaching behaviors and the context in which they occur, with which teachers learn how to make choices about educational goals and practices (Kennedy, 1989). Therefore, reflective teachers can look back on classroom events, make judgments about them in context, and alter their teaching behaviors (Valli, 1997). Research indicates that PTs who are taught how to be reflective can see the interrelatedness of seemingly isolated classroom phenomena (i.e., class discussions, student questions, homework solutions) and tend to take responsibility for teaching problems rather than blaming students for not learning or not being motivated (Kleinfeld & Noordhoff, 1988). On the other hand, research shows that teachers who are unreflective tend to be limited in their ability to make good decisions, consider the consequences of their actions, or to alter their actions (Borko, Eisenhart, Kello, & Vandett, 1984).

Zeichner (1987) proposed that there are several strategies that teacher education programs can implement to enhance the reflective capabilities of PTs. These strategies include: (a) action research projects, (b) ethnographic studies in which PTs spend time in schools studying various aspects of the classroom such as teacher-student interactions, (c) writing in multiple forms such as journals, (d) reflective teaching which involves repeated cycles of planning, teaching, testing, and reflecting, and (e) curriculum analysis and development. Although Zeichner (1987) justified the value of all of these reflective practices I wish to highlight the use of reflective writing since these types of artifacts were used as data sources in the investigations I conducted.

Reflective journals and writing assignments (i.e., reflection papers) have been used in a number of ways to encourage reflective thinking (Valli, 1997). Yinger and Clark (1981), along with others (e.g. Walker, 1985; Stover, 1986) have argued that reflective writing in the form of reflection papers stimulates higher level thinking and increased awareness of personal values and implicit theories through which one approaches experience. Further, writing assignments allow PTs the opportunity to analyze their goals, successes, and failures so that each situation affords professional growth (Valli, 1997).

Analyzing reflective artifacts such as reflection papers can be used in studying the development of awareness of student thinking because they help capture and measure the practices involved in noticing. For example, reflection papers are written after the lesson has occurred; thus, all classroom pressures are eliminated. Analyses of these papers will allow teacher educators to determine what PTs tended to focus on in their lesson and whether their focus was on student ideas (i.e., the first practice of noticing).

However, the development of this precursor to noticing also involves PTs being able to interpret and respond (hypothetically) to student ideas. The remainder of this introduction will focus on one important aspect of instruction that is essential for gathering evidence of student thinking, namely assessment. I focused on assessment because it is probably the simplest means for teacher educators to analyze for PTs and it is the most accessible. Analyzing PTs interpretation of assessment artifacts can measure the development of the last two practices of noticing- specifically interpreting and hypothetically responding.

1.1.4 Assessment and developing an awareness of student thinking.

Developing an awareness of student thinking does not only involve noticing student ideas, it also includes PTs being able to interpret and critically analyze what they notice so that they can adjust their instructional practices accordingly. Formative assessments are the activities that teachers engage in during instruction in order to produce information about student understanding that can facilitate adaptations of instruction (Sadler, 1989). By engaging in formative assessments teachers are able to address what students are having difficulty with because they are looking for evidence of student learning (i.e., questions, comments), thereby, adjusting instruction as needed (Erickson, 2007).

Several researchers have studied how PTs think about, design, and use assessments. Friedrichsen et al. (2009) found that years of teaching experience influenced the types and timing of assessments, specifically novice teachers did not readily implement formative assessments. Moreover, novice teachers waited to grade worksheets and used the grades on the worksheets to inform their instruction in subsequent lessons.

Research in teacher education has elucidated some of the naïve conceptions of assessments generally held by PTs (Buck, Trauth-Nare, & Kaftan, 2010). For example, PTs generally hold a “get it or don’t get it” conception of student’s knowledge which has significant implications on the types of assessments they implement and the ways they interpret student responses (Otero, 2006).

Given the difficulties novice teachers experience with regard to assessment practices, Harlan and James (1997) argued that PTs need to develop the necessary skills to engage in formative assessments more readily. The skills involve interpreting evidence from the classroom and making use of this new knowledge in their lesson. In order to develop these skills, PTs need to first collect evidence in the form of student responses on the lesson topic. Once the PTs have identified this evidence their interpretation should be in terms of what to do to help further learning (Harlan & James, 1987).

To develop these skills, Furtak et al. (2010) argued that PTs need to follow a specific framework for effective formative assessment practices. The first step of this framework involves setting a goal, which includes identifying a target understanding or ability for students. Next, the PTs must determine what students know. To identify the prior knowledge of the students, the PTs need a strategy or prompt for making student thinking explicit. Some of these strategies could include listening to student ideas in small group talk, reading over student written work, and asking specific questions. Once a PT has assessed the gap between student thinking and desired learning goals, the final step is to provide the student with feedback to improve performance in the direction of the learning goal (Furtak et al, 2010). In order to fully implement the framework put forth by Furtak et al, (2010), it is important for PTs to understand how learning should progress in order to enable them to see where the students are on this learning trajectory.

As evidenced above, formative assessments entail different types of skills and knowledge needed by teachers, such as content knowledge, the skill of interpreting evidence from student artifacts, and making use of this new knowledge to determine the students underlying misunderstandings. Novice teachers tend to struggle with these essential skills that are needed to engage in formative assessment (Friedrichsen et al., 2009). For example, in their review, Davis et al. (2006) contended that even when PTs engage in formative assessment they often lack the knowledge of what to do with the evidence (i.e., student ideas) that surfaced. Given the studies reviewed thus far, it is clear that PTs struggle with implementing formative assessments for various reasons, such as their difficulty in determining what constitutes as evidence of student learning, their interpretation of this new knowledge to identify student misunderstandings (e.g., Harlan, 2005), and their limited knowledge of assessment practices (e.g., Maclellan, 2004). In order to alleviate this difficulty, PTs must begin to think about assessments differently. For example, Stiggins (2001) argued that PTs need to develop a new way of thinking that balances assessments *for* learning with assessments *of* learning. Stiggins (2001) contended that this view would allow PTs to see the necessity of providing information back to students in ways that enable these students to learn better. Others, such as Earl (2003) advocated for synergy among assessments *of* learning (summative), assessments *for* learning (formative), and assessments *as* learning (this is an ungraded assessment in which students monitor their own learning).

PTs must recognize the different purposes of assessment by shifting their paradigm to understand how assessment can drive instruction and positively impact student learning and performance (Volante & Fazio, 2007). However, there has not been much research conducted on how to shift PTs understanding of assessment. Buck et al. (2010) contended that in order for PTs to see the connection between interpreting student ideas and changing instruction accordingly, teacher education programs must make formative assessment practices more recognizable. In their study, formative assessment practices guided all aspects of the semester long methods course including instructional planning as well as teaching and learning strategies implemented during class periods. For example, all PTs enrolled in the methods course were required to conduct a case study of teaching science with elementary students in an afterschool science class in which they worked with these students once a week for five weeks. The PTs created and implemented instructional plans that focused on formative assessments, including: (a) a pre-assessment plan to probe students' prior knowledge; (b) research on a specific instructional topic and development of lessons that addressed the goals; and (c) embedded formative and summative assessment plans for the entire unit. Buck et al. (2010) concluded that PTs gained a more sophisticated understanding of formative assessment which was evident in the PTs' ability to incorporate formative assessment into instructional lesson plans, implement planned assessments, and describe students' conceptions prior to instruction.

1.1.5 Overview of the three studies.

The following three studies take different approaches to address the question: *How do preservice teachers develop an awareness of student thinking?* This question serves to examine how the precursors to noticing, specifically framing and developing an awareness of student thinking evolve over the course of a teacher education program. Findings from these studies contribute to the literature by demonstrating how PTs attend to student ideas to drive hypothetical follow- up lessons.

In the first study (chapter 2), I analyzed three reflection papers that were written over the course of the teacher education program. This study examined the first precursor to developing an awareness of student thinking, *framing.* In this investigation, I explored what components of student thinking were noticed by PTs in their written reflection papers. I then characterized the various frames that the PTs employed while reflecting on their lessons. I wanted to identify what degree (if at all) the PTs placed on attention to student thinking.

Attending to student ideas is comprised of several different skills, thus in the second study (chapter 3), I examined how PTs assessed student understanding by analyzing the PTs reflections papers in which they evaluated student thinking in terms of scientific content and scientific practices. I explored how their assessment of student ideas changed over the course of the two year teacher education program. In addition, I also investigated in what ways the PTs used their analysis of student artifacts to guide instructional design.

The final study (chapter 4) examined how the three skills in developing an awareness of student thinking, specifically attending, interpreting, and hypothetically responding changed throughout the teacher education program. I explored the development of these skills by analyzing the PTs responses to interview questions in which they were asked to assess student models. I was interested in uncovering whether the PTs were more descriptive or interpretive in their analyses. I also explored how their analyses of student models impacted their suggested hypothetical follow-up lessons. A second component of this study examined how experienced inquiry teachers attended to student ideas. My goal for this part of the investigation was to determine how years of experience impacted attention to student thinking.

Findings from all three investigations have several implications to teacher educators. The results from the various studies will advance our understanding how the precursors to noticing, specifically framing and developing an awareness of student thinking, change over time. Researchers, such as Tabachnik and Zeichner (1999), found that PTs do not account for student ideas; however, my investigations have eliminated the dynamic nature of a real classroom environment; thus, the results can indicate how (if at all) PTs accounted for student thinking without the pressures of the classroom interactions. Establishing this baseline how the PTs account for student thinking will then allow teacher educators to develop more appropriate pedagogical tools to be used in methods courses. These investigations also have a methodological implication. In the past, the construct of framing and noticing has been studied using videos. These investigations that I conducted will provide insight if these constructs and their precursors can be studied using static artifacts, such as reflection paper and student written work.

Chapter 2:

Framing reflections on instruction:

A precursor to noticing

Abstract

Noticing is the ability of teachers to attend and interpret student thinking to guide instructional design (van Es & Sherin, 2002). The skills involved in noticing can be challenging to develop in teacher education programs because of the cognitive load involved in attending to the dynamic context of the classroom in real time. Teacher education programs may be better positioned to develop a precursor to noticing we term *framing*. Framing or frames are lenses of instruction that involve developing a range of "seeing" events in the classroom. Thus, preservice teachers must frame their teaching experience in ways that privilege student thinking. In our investigation, we characterized the frames preservice teachers employed in reflections on instruction episodes. We found that the frames the preservice teachers employed had varying degrees of attention to student learning. Throughout the course of the teacher education program, we observed a slight shift in the frames the preservice teachers employed in that they began to use frames that were more attentive to student thinking. In addition, we found that preservice teachers who used frames that were more attentive to student ideas were more interpretive of student understanding when analyzing written student artifacts

2.1 Introduction

Over the past three decades, standards documents have emphasized the need to engage students with the epistemology and practices of scientific inquiry (National Research Council [NRC], 1996, 2007, 2011). Since teachers mediate students' science learning, it is imperative that teachers develop the knowledge and practices to implement inquiry teaching (Abd-El-Khalick & Lederman, 2000). A key factor in implementing inquiry-based teaching is the ability to attend to and interpret student ideas and to use such interpretations to guide instructional design (van Zee & Minstrell, 1997). The idea of attending to student thinking is not new- it has been a core aspect of pedagogical content knowledge (PCK) models for decades (e.g., Grossman, 1990; Magnussion, Krajcik, & Borko, 1999). More recently, Windschitl et al. (2012) advocated the need to use instructional tools that support ambitious teaching, including strategies that help teachers attend to student ideas. However, despite the need to and benefits of attending to student thinking, this practice poses a major obstacle for experienced teachers and is even more difficult for preservice teachers (Chamberlin, 2005). In particular, preservice teachers (PTs) struggle to make sense of student ideas and to develop these naïve ideas towards more normative understandings (Friedrichsen et al., 2009). The skills involved in noticing student ideas can be difficult to develop in teacher education programs because of the cognitive load involved in attending to the dynamic context of the classroom instructions. Thereby, teacher education programs may be better positioned to develop a precursor to the skills of noticing, which we term *framing*. In this investigation, we examined the development of framing in a science classroom by evaluating PTs' reflection papers.

2.2 Theoretical Framework

In every field, experts have the ability to notice and interpret events in their domain- they have what Goodwin (1994) termed "professional vision". Building on Goodwin's ideas, van Es and Sherin (2002) developed the framework of "noticing" to capture the notion of professional vision in teaching. The ability to notice consists of three sub-skills: (a) identifying what is important, (b) making connections between the specifics of classroom interactions, and (c) using what one knows about the context to reason about the classroom situation. Sherin et al. (2008) contended that the development of these skills is difficult because classroom interactions, the fodder for noticing, are often fleeting and several interactions may occur simultaneously. It is even more challenging to help PTs develop these skills due to the cognitive load involved in attending to the messy and dynamic contexts of real classroom interactions. Obtaining videos of PT instruction can also pose logistical challenges.

To circumvent these issues, teacher educators can focus on the development of precursors to noticing. We propose framing instruction as being about student thinking as a precursor to noticing. Hammer et al. (2005) termed frames as lenses to instruction and argued that framing involves developing a range of "seeing" events in the classroom. The framing construct has initially been used in research on physics education, which has shown that how students' frame the learning activity is reflected in their reasoning patterns and behavior (Reddish, 2004; Rosenberg, Hammer, & Phelan, 2006). For example, when presented with a physics problem one student may frame the problem as an equation to be solved, thereby, identifying variables, plugging them into an equation to solve. Conversely, another student frames the problem as an occasion for intuitive sense making, thereby, constructing a narrative of the mechanisms noted in the problem.

More recently, this construct of framing has been used in teacher education to describe the different ways in which teachers view classroom events. Levin, Hammer and Coffey (2009) found that whether and how teachers attend and respond to student thinking largely reflects how they framed what was taking place in their class. Therefore, a frame refers to expectations an individual has about a situation that affects what they notice and how they act. In order to develop the skills necessary for noticing, PTs must first frame their teaching experience in ways that privilege student thinking such that they observe these ideas and are subsequently able to interpret and respond to them.

Most of the research about framing was based on analysis of videos of PTs' teaching. However, we wanted to investigate whether we could measure framing through written reflection papers. Researchers, such as Cavanaugh & Prescott (2010) and Hatton & Smith (1995), advocated for the use of reflection in teacher education programs as a vehicle to shift PTs attention away from themselves and towards attending to students thinking. Further, reflection fosters personal and professional growth, which has shown to improve teachers' knowledge and awareness of their classroom practices, including developing an awareness of student ideas (Baird et al., 1991). Due to these benefits of engaging in reflective practices, we felt that reflective practices would be an appropriate way to examine if PTs were capable of attending to student thinking. Engaging PTs in reflective practices could also be a productive way to study framing because how the reflection is framed places an emphasis on learning through questioning and investigation since it occurs after the lesson was taught, thereby, eliminating all time constraints and other classroom pressures. By characterizing the frames that are expressed, teacher educators may be able to examine the various ways PTs attend to student ideas as well as study the development of framing. Further, some research on noticing suggested that PTs change throughout a teacher education program; thus, it may be that PTs first need to develop the precursor to noticing. Thereby, it is important to examine the development of framing over the course of a teacher education program. Our research questions for this study are:

1. To what extent do PTs' framing of their lesson reflections privilege attention to student thinking?
2. How do the frames expressed by PTs change over the course of a two-year teacher education program?

2.3 Methods

2.3.1 Study Context

This study was conducted in the context of a two-year Ed.M. certification program for secondary biology teachers. There were sixteen PTs enrolled in the program. Four of the PTs were males and twelve were females. Fifteen of the PTs were Caucasian while one was of Asian descent. All of the PTs' undergraduate degrees were in the biological sciences with nine having biology degrees, three having animal science degrees, three having environmental science degrees, and one having a molecular biology degree.

The two year Ed.M. program included four life science methods courses that were taken in sequence (including a seminar that accompanied student teaching). The methods courses were geared to the development of knowledge and practices of model-based inquiry instruction. Each methods course had a slightly different focus. The first course, *Methods I*, focused on developing PTs knowledge of the nature of scientific inquiry. *Methods II* was a design course in which the PTs worked in groups to design an extended inquiry-based unit as well as implemented a short inquiry-based lesson. *Methods III*, which accompanied the student teaching internship, focused on the implementation of inquiry-based instruction as well as reflecting on their instructional methods. The majority of the PTs (fifteen out of the sixteen) completed their student teaching practicum in suburban high schools in the northeast while one of the PTs completed the requirement at an inner city high school in the northeast. Finally, the last course, *Methods IV,* engaged teachers in action research using data they had collected during their student teaching internship. The data that we used in this study was taken from *Methods II* and *Methods III.*

2.3.2 Data Collection

In this study, we used four assignments from *Methods II* and *Methods III*: (a) teaching experiment reflection paper from *Methods II*, (b) lesson set I and II reflection papers from *Methods III* and (c) reflective journals from *Methods II* and *Methods III.*

Teaching experiment reflection. The PTs were required to teach a lesson during the second methods course as part of their fieldwork and were asked to write a reflection paper about their experience. The reflection paper was divided into three sections. In the first section, the PTs were asked to provide a description of what went well and what did not go well in the lesson. In the second section of the reflection paper, the PTs were asked to select written student artifacts from the lesson and analyze the artifacts for student understanding in terms of scientific practices and content. In the third section of the paper, the PTs were asked to reflect on the revisions they would make to this lesson. In this study we analyzed the first two sections of the reflection paper.

Lesson set reflection I and II. During the third methods course, the PTs were asked to develop and implement two inquiry-based lesson sets during their student teaching practicum. Lesson set I was completed early in the semester (weeks 4-7) while lesson set II was completed towards the end (weeks 10-14). The lessons had to focus on model-based inquiry instruction. After implementing the lessons, the PTs were asked to provide a description of the lesson as well as to select written student artifacts from the lesson to analyze for student understanding in regard to scientific practices and content.

Reflective journals. The PTs were required to maintain a reflective journal throughout the two courses and to provide entries of about 250-300 words weekly. There were two types of journal entries: (a) answers to prompted questions that we asked several times during the course (i.e. what are the features of a scientific argument) and (b) personal and ‘free-style” reflections on that week’s class.

2.3.3 Data Analysis

We initially blinded all data sources in terms of PT and reflection paper. Using a constant comparative method (Glaser, 1964), we read through the sections of the reflection papers in which the PTs were asked to describe the previously implemented lesson. We noted any emergent frames the PTs expressed. A frame was defined as the interpretative lens PTs expressed while reflecting on lessons. For example, a focus on student participation or students staying on task would be categorized as an *engagement* frame. We identified six distinct frames, which we describe in the results section.

We then un-blinded the data to explore trajectories of change in frames the PTs employed over the course of the teacher education program. In addition, we wanted to examine whether the content of the different frames changed throughout the course of the teacher education program. We constructed tables for each frame according to the reflection papers (i.e., three tables for each frame) and coded the content of the statements the PTs wrote about. For example, many PTs wrote about student participation when employing an *engagement* frame for all three reflection papers. We coded the aspects of participation the PTs wrote about such as working collaboratively, quietness of students, and attentiveness of students in the teaching experiment paper and how students asking questions turned the lesson into a heated debate in lesson set II reflection papers. We reported the observed differences in the results section.

After coding for trajectories of change in the types of frames the PTs employed, we observed that some PTs progressed towards employing frames that were more attentive to student ideas while others did not. Out of the sixteen PTs, we noticed that three of the PTs did not hand in one of their reflection papers. Therefore, we selected the remaining thirteen PTs for a more in depth analysis of shifts in the frames they employed- seven of these PTs continually progressed towards framing instruction in ways that were more attentive to student thinking, four PTs selected did not progress (i.e., they either regressed continuously or used the same frame) in the frames they employed, and two PTs regressed and progressed in the frames they employed. We then analyzed the section of the reflection papers in which they were asked to analyze student understanding in written student artifacts that they had collected. We were interested in exploring whether those who employed frames that were more attentive to student thinking were more capable at identifying what students understood in the lesson. We read through that section of the reflection paper and using a constant comparative method (Glaser, 1964) noted any observed differences.

We triangulated the data by reading through journal entries that were written at the time of the implemented lessons (i.e., same time point as the reflection papers) to determine whether PTs expressed similar frames in the journals as were expressed in the reflection papers. We chose to use journal entries as a way to triangulate our data since writing in journals can be considered another type of reflective practice. We established inter-coder reliability by having two independent coders code the reflection papers (reliability ranged between 95-97%); any disagreements were resolved and codes were adjusted to reflect the consensus.

2.4 Results

2.4.1 To What Extent Do PTs' Framing of their Lesson Reflections Privilege Attention to Student Thinking

We identified six emergent frames described in table 2.1. We found that the framings of the reflections by the PTs attended to student understanding and student ideas to varying degrees. Table 2.1 presents the frames from the least to most attentive to student understanding. For example, PTs who employed the *engagement* frame focused on the students' interest and participation in a lesson with not much emphasis on student thinking. On the other hand, frames such as *scientific practices- students* and *building ideas* attended to student understanding in either scientific inquiry practices or scientific content. These results are encouraging because they illustrate that some PTs are able to attend to student thinking and that attention to thinking is a salient aspect of teaching for them. However, some PTs tended to frame their reflections in ways that did not take into account for student ideas, such as *activity sequence* frame. In general, we found that PTs tended to express one frame or at most two, specifically in the teaching experiment paper. It also seemed that the PTs tended to employ the same frame regardless of the assignment (i.e., reflection paper versus journal prompts that were written around the same time as the reflection papers).

Table 2.1: Descriptions of emergent frames observed

Frame	**Description of the Frame**	**Example from Reflection Paper**
Activity Sequence	Characterized by a focus on providing a narrative or description of the lesson with minimal to no reflection	"The students worked with the person they were sitting next to and talked about what they think happened in the story. After a little bit of time, volunteers read aloud their answers." (Nina, Lesson Set II)
Scientific Practices-Teacher	Characterized by a focus on the teachers actions as they related to scientific practices, such as modeling, argumentation, etc.	"I handed each student modeling worksheets. Being as modeling is not something my students are familiar with, I felt it was necessary to help get them started so I wrote down the first two steps in the sequence of a fever with arrows on the board." (Jake, Lesson Set I)
Engagement	Characterized by a focus on student interest, participation, and staying on task.	"The story part went well, both periods were quiet, listening, and for the most part seemed interested." (Molly, Teaching Experiment Paper)
Accuracy	Characterized by a focus on obtaining the right answer. Teacher interprets student understanding in a binary way, either as correct or incorrect.	"The students demonstrated a basic form of knowledge of the content but did not go into much detail at all. A few students came up with the idea that antibodies were in the body." (Bani, Lesson Set I)
Scientific Practices-Students	Characterized by a focus on students' actions while implementing scientific inquiry practices such as	"None of the students used the data for generating evidence for claims, like viruses have various proteins…they [the students] failed to connect (link) data to evidence

	modeling and evidence-based argumentation.	when making individual models." (Patrick, Lesson Set I)
Building Ideas	Characterized by a focus on taking students' knowledge and building upon it. Teacher interprets student's current level of understanding and describes possible connections to other content or suggests material to facilitate desired connections.	"By evaluating the worksheets I was able to provide material to help them [the students] more fully understand the implications of their solutions on the system as a whole by providing examples of previous attempts and solutions or additional data about the factors they involved." (Rachel, Teaching Experiment Paper

2.4.2 How Do the Frames Expressed by PTs Change over the Course of a Teacher Education Program

Initially the PTs tended to focus on the interest and participation of the students and there was a small shift towards focusing on student thinking (table 2.2). Additionally, in examining how individual PTs shifted throughout the course of the teacher education

Table 2.2: Frames observed according to reflection papers

Frame	**Teaching Experiment Paper**	**Lesson Set I**	**Lesson Set II**
Activity Sequence	0	3	3
Scientific Practices-Teacher	1	3	0
Engagement	13	3	3
Accuracy	2	3	0
Scientific Practices-Students	1	3	6
Building Ideas	1	1	3

program, we noticed that many of the PTs used different frames than they had employed in their first reflection paper with some PTs using frames that were more attentive to student ideas. For example, during *Methods II* Sean wrote, “The lesson flowed smoothly. The students were engaged and the transitions between activities really caught their attention.” Sean expressed an *engagement* frame highlighting the alertness and time on task of his students. Conversely, during *Methods III*, Sean’s focus shifted to a *scientific practices- student* frame highlighting students’ engagement in scientific modeling: “The best part of the lesson was when the students were working with their models. They were able to construct logical representations of the material we had just covered.”

Similarly, Jackie in her teaching experiment paper wrote “I found the students were very willing to participate in a respectful manner, raising their hands before speaking or calling out when there were no other hands raised.” Like Sean, Jackie expressed an *engagement* frame because her focus was on the students’ participation in the lesson. However, during *Methods III,* Jackie’s focus shifted to a *building ideas* frame highlighting students’ elaboration and connections amongst topics:

> “I made a concept map on the board but the map was really made entirely by the students as I would not write anything on the board until they discussed the ideas and concluded it was important to include. The students were able to take their initial ideas and elaborate and build upon them until they fully expressed their understanding.”

Further, we observed this shift in both the reflection paper and reflective journal prompts. Table 2.3 below lists the frames employed by each PT for the three reflection papers. The table is color coded with the frames that were most attentive to student ideas in green, the frames that had minimal attention to student ideas in yellow, and the frames that were not attentive to student thinking in red.

Table 2.3: Frames expressed by PTs throughout the teacher education program

	Teaching Experiment Paper	**Lesson Set I**	**Lesson Set II**
Christine	Engagement	Activity Sequence	Engagement
Patrick	MISSING DATA	Scientific Practices- Students	Engagement
Jackie	Engagement	Scientific Practices- Teacher	Building Ideas
Nina	Engagement	Engagement	Activity Sequence
Jack	Engagement	Accuracy	Building Ideas
Catherine	Engagement	Engagement	Activity Sequence
Sean	Engagement	Accuracy	Scientific Practices- Students
Nora	Engagement	Scientific Practices- Teacher	Activity Sequence
Molly	Engagement	Scientific Practices- Students	Scientific Practices- Students
Nadia	Engagement/Scientific Practices- Students	Activity Sequence	Building Ideas
Ava	Engagement/Scientific Practices- Teacher	Scientific Practices- Students	Scientific Practices- Students
Bani	Engagement/Accuracy	Accuracy	Scientific Practices- Students
Jake	Engagement/Accuracy	Scientific Practices- Teacher	Scientific Practices- Students
Clare	Engagement	Engagement	Scientific Practices- Students
Rachel	Building Ideas	Building Ideas	MISSING DATA
Anna	MISSING DATA	Activity Sequence	Engagement

*We assigned a "missing data" code if PTs did not submit an assignment

In addition to how the frames employed changed throughout the course of the teacher education program, we also wanted to explore whether the content of the different frames changed. We found that PTs began to be more elaborate and detailed in their descriptions of students' ideas in certain frames, specifically *scientific practices- students* and *building ideas.* Initially many of the PTs, who employed these frames, commented that the students had a difficult time explaining their models. They made statements like "the students did not explain or justify their models." However, in later reflections the

PTs became more nuanced and explicit about *the ways in which* the students had difficulty using data stating, “the students’ content knowledge ability impacts how they understand the data and how they support their models” and “the students interpreted the data from the experiments and activities we performed in class and were able to incorporate this data to provide evidence based explanations.” It seemed that the PTs began to see how different aspects of their students’ learning process impacted their modeling skills. Overall, this shift was observed by all the PTs who employed *scientific practices- students* and *building ideas* frames in *Methods III.*

In addition, we found that there was a shift in the frequency with which PTs used students’ responses in the form of quotes or comments from lesson activities when comparing the teaching experiment paper and the lesson sets even though the reflection instruction prompts were identical. Initially, none of the PTs cited student responses in their reflection papers written for *Methods II,* while the majority of PTs used statements from students in their Lesson Set II reflection papers (table 2.4). It seemed that as the PTs gained more experience in the classroom through their student teaching practicum, they became more aware of what students were saying and began to use the students’ responses as evidence for justifying their reflections.

Table 2.4: Number of PTs who cited student responses in their reflection papers

	Teaching Experiment Paper	**Lesson Set I**	**Lesson Set II**
Number of PTs Who Used Student Responses	0	13	14

Although we did not observe a significant shift in the frames the PTs employed throughout the teacher education program, we wanted to explore in more depth the reflections written by the PTs who progressed towards framing instruction in ways that were more attentive to student thinking such as Sean, Ava, and Molly (to name a few). We found that in the earlier reflection papers, there were "seeds" of frames that were more attentive to student ideas such as the *building ideas* frame. For example, in the teaching experiment paper, Sean's main focus was how the students participated in the lesson (*engagement* frame) but there were several statements about "bringing out student ideas", which are aspects of frames that are more attentive to student thinking, such as *building ideas* and *scientific practices- students* frames. Similarly, Ava's main concern in the teaching experiment paper was with the students being on task during the activity (*engagement* frame) but Ava made a few comments about "connecting ideas amongst topics as an effective instructional strategy", which is an aspect of the *building ideas* frame. Although Ava, Sean, and other PTs' focused mostly on student participation and interest in earlier reflection papers (*engagement* frame), it seemed that in order to progress toward frames that were more attentive to student ideas there has to be an initial "seed" that becomes more prominent with experience.

Lastly we analyzed the section of the reflection papers in which the PTs were asked to analyze student understanding in the lesson. We wanted to examine whether the PTs who employed frames that were more attentive to student thinking, such as Sean, Ava, and Molly (to name a few) were more attentive to student understanding in their analyses as compared to PTs who employed frames that were minimally attentive to student thinking such as Catherine, Nina, Nora, and Christine. In general, we found that

PTs who progressed in how they framed instruction were more capable at identifying what students did not understand, commenting on students' prior knowledge or suggesting what topics should be stressed to learn the material. We also observed that the PTs were better at examining student understanding as the frames they employed were more focused on student thinking.

For example, in his teaching experiment paper, Sean, who throughout the teacher education program shifted towards employing frames that were more attentive to student thinking, commented on what the students were not grasping in the lesson stating, "Every student verbally told me that onion cells do not have chloroplasts and elodea cells do, but many of their diagrams of onion cells included chloroplasts so I don't know where the disconnect is." In this example, Sean does not know why the problem exists or what to do about it; however, his critical analysis highlights an important mismatch between what the students are saying and what they are writing. It seemed that the PTs who progressed did not necessarily have a better understanding of what do with student ideas, but they were better at critically examining student thinking. Conversely, Catherine, who shifted towards employing frames that were less attentive to student thinking, commented in the teaching experiment paper, "I think the students have a general understanding of what makes up a vertebrate" with no further elaboration. In both these instances, Sean and Catherine employed an *engagement* frame when reflecting on their lessons but there is a significant difference in how they interpreted student thinking with Sean being much more specific about what the students were not understanding and providing evidence to support his claim.

In the final reflection paper, lesson set II, Sean, who employed a *scientific practices- students* frame, commented on students' drawings in an evolution lesson, he stated:

> "The models [that students drew] imply that the dots and lines among the required species are additional species (ancestors to humans), but the students do not label as such and do not explain them in their description. This shows that these students are missing a concept and are "filling in the blanks" of their understanding with these "dots and lines".

Here, Sean interpreted student understanding based on the lack of details in the students' models, which he believed indicated a missing connections across scientific ideas, in this case the evolution of species from common ancestors. In Catherine's final reflection paper (she employed an *activity sequence* frame), she stated, "Initially a majority of the students thought that bones are alive. They justified their opinion with correct ideas about the characteristics of living things." Catherine further elaborated her analysis by citing a student response from the lesson stating: "In Mala's model she wrote, "I think they [bones] are (alive) because when the body grows the bones grow too. All living things that have bones grow." However, although Catherine's analysis of student understanding was more evidence based (i.e., provided a response from a student) than in her initial reflection paper, she was still not as attentive to student understanding in regards to the students' overall learning process, whereas, Sean was much more analytical in his reflection by providing suggestions for what missing details in students' models suggested about their overall learning. In general, it seemed that the PTs who progressed in using frames that were more attentive to student thinking were more analytical in their examination of student understanding.

2.5 Discussion

This study examined *framing,* a precursor to noticing. We chose to examine a precursor to noticing, such as *framing,* because it occurred after the lesson was taught; thereby eliminating the cognitive load of a real classroom environment. In this investigation, we were interested in exploring the frames PTs used when reflecting on previously implemented lessons. Overall, we characterized six novel frames that PTs employed. These frames accounted for student thinking and student ideas to varying degrees with the *activity sequence* frame simply being a narrative of the lesson with no attention to students' ideas and the *engagement* frame being about the interest and participation of the students in the lesson. Davis et al. (2006) argued that when PTs attend to learners their reflection centers on students' interest and motivation rather than learning content, which we also observed here.

Conversely, the *scientific practices- students* and *building ideas* frames had a stronger focus on student thinking by looking at the students actions in an inquiry based lesson as well as looking at the connections between topics and lessons. Although we did not observe any significant shifts in the frames the PTs employed throughout the course of the teacher education program, we did observe a slight change towards use of frames that were more attentive to student thinking such as the *scientific practices- student* frame and the *building ideas* frame. It seemed that as the PTs gained more experience working with students in a classroom (via student teaching internships in Methods III), they began to shift their focus from noting whether students were being on task to becoming more aware of student discourse and how their ideas related to core concepts. Thus, it seemed that more classroom experience tended to support a shift from a focus on themselves to a focus on students' thinking (Berliner et al., 1988).

Overall, most PTs employed one frame when reflecting on their lessons; however, we did observe that in the first reflection paper, the teaching experiment paper, four of the PTs, employed two frames. This was interesting because the teaching experiment paper's instructions were slightly different than the other reflection papers in that we specifically asked the PTs to describe what went well in the lesson and what did not go well in the lesson while in the other reflection papers we asked them to provide an overall description of the lesson. We noticed that for these four PTs they used different frames when reflecting on the positive versus negative aspects of the lessons. When reflecting on the positive aspects of the lesson, all four of the PTs employed an *engagement* frame, but two out of the four PTs varied in the frames they employed when reflecting on the negative aspect of the lesson.

These results suggested that the nature of how the assignment instructions were written could potentially impact how the PTs frame the situation. Boud and Walker (1998) argued that framing situations includes assumptions and provides a language for describing and analyzing what we do. It seems that in this investigation, the PTs framed the situation with the assumption that a lesson was going well if the students were participating; hence, all the PTs employed an *engagement* frame. However, when asked to comment on the negative aspects of the lesson, the PTs framed the situation differently; thus, using different assumptions and lenses of analysis. Therefore, when asked to reflect on the good aspects of the lessons, they framed the lesson in one way and subsequently framed the lesson in another way when asked to describe the negative aspect of the lesson.

Another aspect of our results we found interesting were the differences between the PTs who progressed toward using frames that were more attentive to student thinking and those who did not progress. It seemed that the PTs who progressed had “seeds” (i.e., slight focus but not the main focus of the reflection paper) of other frames that were more attentive to student ideas in their initial reflection paper and as they engaged in more reflective practices those “seeds” began to be more prominent in the lens they used to reflect on the lesson. This shift in frames could be linked to a continuum of reflectivity from a commonsense thinker (PT focuses on themselves) to a pedagogical thinker (PTs attention shifted from themselves to their students) (Laboskey, 1991). It seemed that in order for PTs to shift to pedagogical thinking and frame reflections in ways that are more attentive to student ideas they must have that initial “seed” while those who did not progress stayed as commonsense thinker or used frames that were more attentive to themselves.

Further, we also observed that the PTs who did progress in the frames they employed were more capable at analyzing student understanding in written student artifacts. They were more interpretive in what the students did not understand and they commented on the students’ prior knowledge and how that could potentially impact their learning process. It seemed that these PTs shifted from description to interpretation in reflection (Rodgers, 2002). Hence, they applied a more analytical or interpretive lens when examining student artifacts rather than simply describing what the students did or did not understand. Based on our results, we conjecture that framing in ways that privilege student ideas may be a productive precursor to attending to student thinking in real time; thus, if the PTs were able to frame instruction in a way that privileged student thinking than they would be more capable at developing the skills of noticing in a real time environment. However, we suggest further research should be conducted to examine the relationship between *framing* and noticing.

2.6 Implications and Limitations

We observed a slight shift towards employing frames that were more attentive to student thinking as the teacher education program progressed. This is encouraging because it suggested that engagement in reflective practices, such as journal writing and reflection on previously implemented lessons, may shift the PTs focus to students understanding. Engaging in these practices could promote critical analyses skills in which the PTs begin to reflect on their lessons in a more analytical way by examining how classroom interactions impact student learning. Thereby, we suggest that teacher educators should engage PTs in various reflective practices throughout the course of the program. Providing the PTs with these opportunities may encourage them to employ frames that attend to student thinking and thus PTs will be more capable of analyzing student understanding in written student artifacts, an essential skill they will need in their future teaching career. Additionally, our findings suggested a methodological implication. In the past the notion of framing has been studied using videotape analyses but our results indicated that framing can be examined through analyses of written work, such as reflective practices.

We would also like to discuss some of the limitations of this study. The scope of our investigation was to look at one cohort of teachers, thus our sample size was relatively small; thereby, impacting the number and types of frames that we were able to observe and characterize. We feel that a larger sample size may lend itself to further frames that we did not observe in this study. In addition, it seemed that how we phrased the instructions of assignments could have affected what PTs attended to and consequently the frame that they employed. However, in this investigation we have no evidence either way to support or refute this idea; thus, this could be a potential limitation. Finally, even though our results suggested that PTs began to employ frames that were more attentive to student thinking in their reflection papers, we did not monitor the PTs in their first year of in-service teaching; hence, we have no evidence as to whether they were more attentive to student ideas in the classroom.

Chapter 3:

Examining preservice teachers' ability to assess student learning

Abstract

Assessing student understanding is a key component of responsive instruction. In the context of teacher education, engaging preservice teachers in the analysis of written work could enhance teachers' attentiveness to student understanding and enable them to monitor student progress in more nuanced ways (Kazemi & Franke, 2004). In this study we examined how preservice teachers assessed student understanding in their analysis of written student artifacts. Our findings suggest that as the program progressed teachers shifted from evaluating a single artifact in simple and uni-dimensional ways to sophisticated interpretations of student thinking based on artifacts evaluated along multiple dimensions. In addition, we observed that PTs began to use their interpretations of student understanding to guide their next instructional strategies in the classroom.

3.1 Introduction

The importance of having teachers listen to and assess student ideas is central to reform oriented instruction (Crespo, 2000). Professional standards across domains (i.e., National Research Council [NRC], 2011; National Council of Teachers in Mathematics [NCTM], 1991) highlight the analysis of student thinking as one of the core tasks of teaching. Knowledge of students' conceptions is also a prominent aspect of pedagogical content knowledge (PCK) (Shulman, 1997; Grossman, 1990). Several professional development programs promoted attention to student ideas by having teachers analyze student written work (Jacobs et al, 2010; Kazemi & Franke, 2004). Research has shown that when teachers analyzed their students' work they developed more detailed knowledge of their own students' mathematical thinking and began to shape a particular stance about the role of the teacher, namely: (a) teacher's work involves attending to children's thinking; (b) teachers make public their efforts to elicit student thinking; and (c) teachers recognize student's mathematical competencies (Kazemi & Franke, 2004).

Given the importance of attending to and interpreting student thinking, assessment of student understanding has gained emphasis in teacher education programs (Windschitl, Thompson, & Braaten, 2009). One way to enhance preservice teachers' capacity to interpret and evaluate student ideas is through the analysis of student written work. In contrast to the messiness and overwhelming nature of attending to student ideas as manifested in classroom discourse, written artifacts afford a stable and permanent record of student thinking that can be analyzed and reflected upon. Many researchers (i.e., Ball & Cohen, 1999; Little, 2002) advocate using analysis of student work to promote professional growth because it could potentially shift the teachers' focus from one of general pedagogy to one that is specific to their students (Kazmi & Franke, 2004). However, there is relatively little research on how preservice teachers (PT) assess student thinking in written student artifacts. Much of the existing research in this vein explores how PTs think about, design, and use assessments (i.e., summative versus formative assessment). For example, Campbell & Evans (2000) analyzed over three hundred lesson plans from PTs in their student teaching practicum. They found that the majority of the PTs did not incorporate appropriate assessment strategies to address the instructional goals of the lesson. While we know that PTs attempt to implement assessments, we still do not know how PTs make sense of student thinking as evidenced in these assessments and how they use this information to inform instruction. Given the gap in the research we chose to focus our study on the ways in which PTs attend to student understanding in written student artifacts as well as how they interpret what they attended to in the context of a 2-year K-12 life science certification program.

3.2 Theoretical Framework

Professional vision is the ability of experts to interpret events in their given domain (Goodwin, 1994). A teachers' professional vision includes the core skill of attending to and evaluating student understanding. van Es and Sherin (2002) developed the "noticing" framework to capture teachers' professional vision. This framework is comprised of three professional skills: (a) identifying what is important, (b) making connections between the specifics of classroom interactions, and (c) using what one knows about the context to reason about the classroom situation. However, developing the skills of noticing can be difficult since they occur during instruction (Sherin et al., 2008). Because of the ongoing nature of instruction, it is not realistic to expect that one could "pause" instruction momentarily, ask a teacher what he or she is attending to at the moment, and then continue uninterrupted. This "in the moment" nature of noticing poses challenges for teacher educators. These obstacles include the cognitive load involved in attending to the dynamic context of real classroom interactions along with the logistics involved in attaining videos of PTs' instruction. In our study, we engaged PTs with analysis of student work in order to develop aspects of noticing in a less dynamic and cognitively demanding context.

Engaging in-service teachers in the task of analyzing student work has been widely documented with much success (i.e., Borko, et al, 2008; Cobb, Dean, & Zhao, 2006; Lewis, Perry, & Murata, 2006). Little et al. (2003) investigated various professional development programs in which teachers analyzed student written work. The authors found that teachers became more aware of the students and their learning needs after they engaged in analyzing student artifacts. Similarly, others such as Ball & Cohen (1999) found that written student artifacts supported closer examination of student thinking, learning, and instructional strategies. However, the existing research on PTs engagement in the analysis of student written shows that PTs and novice teachers were less inclined to attend to children's strategies and interpret children's understanding; however, regardless of the level of expertise, teachers had difficulty deciding how to respond in follow up lessons (Jacobs et. al., 2010). It seems that analyzing student written artifacts is beneficial but PTs still struggle with taking student ideas into account in their analyses. To complicate matters, in a science classroom, assessing student ideas is not just about scientific content.

In science education, assessing student ideas relates to two aspects of student thinking- understandings about content and understandings about practice. This focus on science content and practice, and their integration, has taken center stage in standards documents and policy reports such as a *Framework for K-12 science education: Practices, crosscutting concepts, and core ideas* (NRC, 2011) as well as the *Next Generation Science Standards*. One of the core practices emphasized in this framework is scientific modeling. Modeling is an essential practice in science since it aids in the development of scientific understanding (Longino, 2002; Giere, 2004). Thus, researchers have advocated that students should engage in modeling practice in the science classroom (Lehrer & Schauble, 2006; Grosslight, Unger, Jay, & Smith, 1991; Snir, Smith, & Grosslight, 1988). Towards this end model-based inquiry instruction involves students developing models in various forms including text, diagrams, and formulas (to name a few) to explain certain scientific phenomenon, as well as experimenting and revising these models based on data and evidence. Therefore, modeling in classrooms helps make students' thinking visible and can provide teachers with a window into students' understanding of both content and practice (Grosslight et al., 1991; NRC, 2011).

Modeling is one of many ways that PTs can make students' thinking visible. However, regardless of the method chosen to elicit student ideas, research by Davis et al. (2006) concluded that PTs do not have very clear ideas about how to assess students' ideas once they have surfaced them in class discussions. Further, prior research in teacher education has shown that PTs generally hold a "get it or don't get it" conception of student's knowledge which has significant implications on the types of assessments they implement and the ways they interpret student responses (Otero, 2006). Fewer studies have examined PTs use of student artifacts, but have shown that when PTs analyzed student work, in the context of model based inquiry, they began to teach in more reform oriented ways during student teaching and their first year of teaching (Windschitl, Thompson, & Braaten, 2009). Specifically, the authors found that the PTs focused on students' use of evidence based scientific explanations. Given the success of analyzing student written work with in-service teachers as well as its impact on PTs' instructional strategies, we wanted to investigate whether and how analyzing student written work contributed to assessing student ideas in a teacher education program that focused on model-based inquiry instruction. Towards this end, we analyzed reflection papers in which PTs were required to assess student ideas in written artifacts that they collected as part of a lesson they taught. We were interested in uncovering what PTs attended to in regard to student thinking and how they interpreted student understanding. Specifically our research questions are:

1. In what ways do PTs interpret student ideas in written student artifacts?
2. What are the various levels of sophistication at which PTs interpret student ideas?
3. How do the PTs selections of student artifacts determine what and how they analyze student understanding?

3.3 Methods

3.3.1 Study Context

We will be using data sources from a project that was carried out in the context of a two-year Ed.M. certification program for secondary biology teachers at a large public university in the North East. There were sixteen PTs enrolled in the program. Four of the

PTs were males and twelve were females. Fifteen of the PTs were Caucasian while one was of Asian descent. Table 3.1 shows the undergraduate majors of the PTs enrolled in the program.

Table 3.1: Majors of PTs in program

Major	**Number of PTs**
Biology	9
Animal Science	3
Environmental Science	3
Molecular Biology	1

The program included four life science specific methods courses that were taken in sequence (including a seminar that accompanied student teaching). These methods courses were geared towards helping PTs develop their knowledge and practices of inquiry-based teaching. The first course, *Methods I,* focused on developing PTs understanding of the nature of scientific inquiry and the central role of modeling in the development of scientific knowledge. *Methods II,* the second course was essentially a design course in which the PTs worked in groups to design an extended inquiry-based unit as well as implemented a short inquiry-based lesson. *Methods III*, which accompanied the teaching internship, focused on the implementation of inquiry-based instruction as well as reflecting on their instructional methods. The majority of the PTs (fifteen out of the sixteen) completed their student teaching practicum in suburban high schools in the North East while one of the PTs completed the requirement at an inner city high school in the North East. Finally, the fourth course, *Methods IV*, engaged teachers in action research using data collected during the teaching internship. All courses, especially the latter two, included an emphasis on student thinking, and engaged PTs in analysis of student work.

3.3.2 Data Collection

In this study we analyzed three different data sources: (a) teaching experiment paper from *Methods II*, (b) lesson set I reflection paper from *Methods III*, and (c) lesson set II reflection paper from *Methods III.*

Teaching experiment reflection. The PTs were required to teach a lesson during the second methods course as part of their fieldwork. This lesson had to include a core scientific practice of either scientific argumentation or scientific modeling. After teaching the lesson, the PTs were asked to write a reflection paper about their experience. This reflection was divided into three sections. In the first section the PTs were asked to reflect on the lesson implementation. The second part of this reflection focused on analysis of student work. The PTs were asked to: (a) provide a description of the student generated artifacts they collected, (b) provide a description of what they could tell about student understanding of content from the collected artifacts, and (c) provide a description of what they could tell about students' understanding of scientific inquiry practices. The third, and final, section of the paper focused on lesson revision. In this study, we focus on the second section of the reflection paper because we wanted to explore the types of artifacts the PTs analyzed along with how they assessed student understanding based on their analysis of these artifacts.

Lesson set reflection I and II. During the third methods course, the PTs were asked to develop and implement two inquiry-based lesson sets during their student teaching practicum. Lesson set I was completed during weeks 4-7 of the semester while lesson set II was completed during weeks 10-14. The lessons had to focus on aspects of model-based inquiry instruction, such as scientific modeling or scientific argumentation. After completing the implementation of these lessons, they were required to write reflection papers for each of them. In these reflections the PTs were asked to: (a) provide a description of the lesson, (b) analyze and provide evidence of student learning in regard to lesson objectives and provide a description student alternative conceptions/ ideas, and (c) provide a reflection on why certain things occurred in the lesson and describe and justify how they would adjust their lesson in the future. In this study, we focus on the section in the paper in which the PTs were asked to analyze and provide evidence of student learning in regard to the lesson objectives (part b).

3.3.3 Data Analysis

Initially, we blinded all data sources in regard to PT and methods course. We read through the specified sections of the reflection papers in their entirety. We first focused our analysis on the types of student artifacts the PTs chose to analyze. Our goal was to characterize the various types of artifacts PTs analyzed. An artifact was an assignment that the student completed during or after the lesson, which were usually in the form of a worksheet, quiz, or scientific model. Initially, we looked at how the artifacts were constructed- were the questions posed more rote/recall questions or were they higher level thinking questions. We then determined what types of artifacts (i.e., worksheets, student models, etc.) the PTs constructed and analyzed as well as explored if there were any shifts throughout the program. Additionally, we examined if there were changes in the sophistication of the prompts or questions used in the artifacts that the PTs constructed- were the questions being posed also rote/recall questions or did they change to be higher level thinking prompts.

We next investigated how PTs interpreted student understanding (i.e., was it binary- students either understand or they don't or more nuanced and sophisticated). For every PT we created two tables for each reflection paper (total of 6 for each PT) to organize the data. The first table corresponded to their assessment of student thinking as it related to content and the second table corresponded to their assessment of student thinking as it related to scientific practices. We wanted to explore whether certain artifacts were assessed in regard to both dimensions of student learning (i.e., content versus practice) or just one. In each table, we summarized the main points of what PTs were assessing in regard to content or scientific practices. We also noted any rationalizations the PTs used to substantiate their interpretations. We coded rationales as any pieces of evidence or justifications from the artifacts the PTs provided to support their interpretation of student learning. Tables 3.2 and 3.3 are sample analyses tables of one of our PTs for Lesson Set I. We then analyzed our tables as they related to time. We wanted to examine what patterns we saw for each reflection paper. Finally, we compared our patterns for each reflection paper to see how (if at all) the PTs assessments and rationalizations changed throughout the program.

Table 3.2: Example analysis table for assessing scientific content in lesson set I

Preservice Teacher	**Assessment of Scientific Content**	**Rationale of Assessment of Scientific Content**
Christine	Students were able to label the parts of the cell cycle and the cellular processes occurring in each stage and students were able to organize the steps of mitosis (artifact- quiz)	Provided the questions on the quiz and tallies of how many students got each question correct

Table 3.3: Example analysis table for assessing scientific practices for lesson set I

Preservice Teacher	Assessment of Scientific Practices	Rationale of Assessment of Scientific Practices
Christine	Students were unable to expand on their explanation in their initial models	Christine placed models into hierarchical categories based on the use or lack thereof explanations with tallies of how many models fell into each category. Examples of categories would be no explanations, explanation based on prior knowledge, explanation incorporating one piece of data, etc.

Trustworthiness. We used various strategies to ensure trustworthiness of our analyses, including employing peer-checks to enhance validity of our interpretations of the data. We also provided thick descriptions of our methods as well as data in the form of quotes to allow the reader to track and evaluate the evidentiary basis of our findings. We established inter-coder reliability by having two independent coders code the reflection papers (reliability ranged between 97-99%); any disagreements were resolved and codes were adjusted to reflect the consensus.

3.4 Results

3.4.1 In What Ways Do PTs Interpret Student Ideas in Written Student Artifacts

We first wanted to examine how PTs assessed student ideas in regard to scientific content and scientific practices. Our results revealed that in terms of scientific content, the PTs assessed student ideas in three ways: either in the form of *recalling information, understanding the main idea,* or *how concepts were connected*. *Recalling information* referred to assessing students in regard to whether or not they could identify structures, label diagrams, or define specific scientific vocabulary. For example, in the teaching experiment paper, Catherine commented, “Most groups were able to identify the three characteristics of vertebrates- having backbones, closed circulatory systems, and having a higher order nervous system." In this example, Catherine is simply assessing students in regard to whether they can recall the characteristics of vertebrates.

PTs also seemed to assess student ideas in regard to *understanding the main idea* of the unit or topic. In these cases, the PTs viewed student understanding as being rather binary- either the student understood the topic or they did not understand the topic. For instance, on a lesson on atomic models Patrick wrote, "Some students (8 out of the 20) did not understand that electrons were found in the nucleus." Patrick is assessing students as either knowing or not knowing this fact about electrons.

On the other hand, PTs assessed student understanding in regard to *connections between concepts*, which referred to students being able to make connections amongst different topics. For example, Rachel, in lesson set I, discussed how her students were able to make connections from a previous lesson on global climate change and apply that knowledge to the current lesson on populations. She stated:

> "A novel response that I received was "maybe the bighorn sheep populations moved due to climate change." In a previous chapter, the class learned about carbon and how rising levels of carbon dioxide in the atmosphere is contributing to global warming. During the discussion of this chapter on populations, the students learned that rising temperatures are causing problems for organisms today, such as melting polar ice causing habitat concerns for polar bears. While this answer was not strongly connected to the terms learned in today's lesson, I was still

> impressed by the ability of this student to take the knowledge from the previous lesson and apply it to today's lesson on populations."

In this example, Rachel assessed the student based on how the student was able to take information that was previously learned and connect it to the current lesson. Overall, it seemed that initially many of the PTs assessed student thinking in regard to scientific content in terms of *recalling information* and *understanding the main idea* in that approximately 70% of the reflections focused on these types of assessment. However, as the teacher education program progressed, the PTs began to steer towards assessing students' ideas in regard to *connections between concepts* in that over 90% of reflections focused on this type of assessment in lesson set II.

We next explored how PTs assessed student understanding in regard to scientific practices, specifically scientific modeling and scientific argumentation. Initially, we found that the PTs tended to focus on superficial aspects of scientific practices, such as model representations (i.e., labeling, color coding). For example, Bani, in the teaching experiment paper, commented, "Half the students understood how to model and label everything correctly". Table 3.4 below reveals the aspects of scientific practices the PTs initially assessed.

Table 3.4: Components of scientific practices initially assessed

Component of Scientific Practice	Frequency Assessed	Examples
Explanation in Models- use of evidence of data in the model	5	"The students struggled with using data from the experiment while some incorporated the data collected from the lab in their model explanations, many did not."

Justifications in Arguments- how the evidence supports the claim	3	"Many students provided reasoning in their arguments."
Model Representations- how models were constructed such as color coding, labeling	8	"Students differentiated between the different components of the atomic models by using different colors to represent the protons, neutrons, and electrons."

With time the PTs began to shift their focus toward assessing student understanding in more sophisticated aspects of practice such as evidence use and the extent to which students incorporated mechanisms in their models. Further, many of the PTs assessed multiple aspects of the modeling practice per student model rather than just one aspect as they had previously done. For example, Nora assessed the students' models in regard to explanatory mechanism (i.e. explanation of how things function- goes beyond process), integration of key terminology in the models, as well as the presence or lack of explanations (i.e., data/evidence used in the model). Overall, it seemed that the PTs began to shift toward analyzing student understanding in regard to scientific content and practice in a more sophisticated and nuanced way by viewing the interconnectedness of material, whether it was multiple components in scientific models or relationships amongst scientific content.

We next wanted to examine whether the type and structure of the assessment artifacts (tasks, prompts, etc.) impacted how the PTs assessed student understanding. Our analysis revealed that initially the PTs constructed assessment prompts which entailed superficial knowledge to respond. Often, the artifacts did not require higher order thinking in order to address the questions or complete the tasks. For example, Jake initially constructed an artifact that had various diagrams of cells going through cellular division and asked the students to number the diagrams in the correct sequential order. Similarly, Anna constructed a worksheet asking the students to place important scientific discoveries in sequential order based on the dates that they had been performed. In both instances, Jake and Anna were simply asking students to recall information without assessing whether students understood the importance of the process or events. Given the low cognitive demand of the prompts PTs used in their assessment artifacts, it is not surprising that they consequently analyzed student ideas in a less sophisticated manner given the simplicity of the students' responses.

However, as the program continued, the PTs construction of artifacts improved, which could potentially explain the more nuanced ways in which they analyzed student ideas. It seemed that the PTs began to steer away from the recall type questions and began to ask students to explain processes and provide underlying mechanisms, such as constructing models to explain "how glucose turns into fat" or models to explain "why Tommy doesn't have to wear a cast any longer?" These prompts were much more thought-provoking compared to the earlier prompts in that they required multiple pieces of understanding. For instance, to address how glucose turns into fat, the students have to understand several concepts and provide biological mechanisms. Thus, the questions or prompts of these artifacts were much more involved, in that they could not be answered in terms of simple rote information. The construction of these artifacts could have afforded more sophisticated analyses, and may explain why the PTs began to be more sophisticated and nuanced in their assessment of student ideas.

3.4.2 What are the Various Levels of Sophistication in which PTs Interpret Student Ideas

There is a current growing emphasis on evidence-based decision making in instruction. Many states nationwide are advocating for teachers to provide evidence of student learning; therefore, we chose to explore in what ways PTs justified student learning gains. In every reflection paper, we asked the PTs to analyze student understanding in regard to scientific content and scientific practices and to provide evidence from the artifacts in their analyses. Thus, we next focused on the rationales (justification and evidence) the PTs provided in their interpretation of student thinking. Rationales were any pieces of evidence from the artifacts the PTs provided in order to justify their assessment of student learning. In the teaching experiment reflection, there were very few, if any, justifications of what students learned in their reflections. PTs would simply make a claim about their students' understanding without citing any evidence or providing an explanation of how they arrived at this claim. Some PTs, like Eric and Nora, interpreted student ideas and then cited one student response as an example. While, they were using students' responses as evidence to illustrate a point, they did not provide evidence regarding the prevalence of particular conceptions were in their assessment data. It seemed that certain PTs used evidence to support their claim about student understanding but they did not use this evidence to elaborate how the students' responses related to learning gains. Further, in the initial reflection paper, only three out of the sixteen PTs provided quotes from students- none of the other PTs provided any sort of evidence or justification.

There was some improvement in the second reflection paper, lesson set I. All of the PTs justified their assessment of student understanding- thirteen out of the sixteen provided student responses in the form of statements from the students' artifacts that they collected. These were used as evidence to support their claim (an illustrative example or existence proof). However, three of the PTs additionally provided a data table showing frequencies of response types. For example, Sean made a list of the objectives for the lesson and based on his analysis of the students' models, he was able to show how many of the students achieved that goal and how many did not. Sean viewed student understanding as binary but he supported his claims about student learning with evidence. Jackie and Jake's analyses were even more sophisticated in that they categorized students' responses at different levels of understanding, which provided them with a clear assessment of their students' progress in the overall learning process. Jackie's analysis (Table 3.5) focused on the varying degrees of student understanding as it related to the differing mechanisms in the models. This shows a shift from a binary view of "get it or don't" to a more nuanced and developmental, or incremental, view of learning.

Table 3.5: Example of Jackie's analysis of student understanding

Explanation of Category	**Total**
Cell cycle only, including tumor formed from many cells.	1
Mutation/Mistakes in DNA and cell dividing representation. No mention of any mechanism in the cell cycle.	3
Mutation/Mistakes in DNA and proteins with no mechanism. Mitosis/cell division represented and cancer is shown as many cells	3
Mutation/Mistakes in DNA and proteins. These abnormalities in proteins allow the cell growth to occur faster but no specific mechanism given.	2
An imbalance in proteins at checkpoints lead to cell dividing. No mistakes in DNA or proteins.	1

Lesson set II, the final reflection paper had the same instructions as the previous reflections papers. However, we observed a significant improvement in the PTs' justifications of their claims regarding student understanding and learning. Most (thirteen out of the sixteen) PTs created charts in which there were distinct multiple levels of understanding of content knowledge (similar to table 3.5). However, several of the PTs went a step further. For example, Nora compared students' initial and final models (of how a bone heals) using a nuanced scheme of levels of understanding. Through this comparison she was able to justify claims about learning gains. Similarly, Nadia constructed tables to show students' understanding based on their initial models. Using these tables, Nadia was then able to pinpoint what she should focus on in her instruction for the next class. Overall, our findings revealed that PTs provided more sophisticated justifications for student learning as the teacher education program progressed.

3.4.3 How do the PTs Selections of Student Artifacts Determine What and How they Analyze Student Understanding

In the last part of our analysis, we wanted to investigate what types of artifacts the PTs chose to analyze and if there were any changes in the artifacts they chose. As shown in table 3.6, we found that as the program progressed 94% of the PTs shifted from analyzing rote/recall prompts in worksheets on various biological topics like the cell cycle or food chains (to name a few) towards analyzing student models (both initial models which were drawn before the lesson was taught and final models which were drawn after the lesson).

Table 3.6: PTs' artifact selection throughout the program

	Teaching Experiment Paper	Lesson Set II
Artifact	**Number of PTs**	**Number of PTs**
Rote/Recall Prompts in Worksheets	9	0
Lab Write-Ups	0	1
Class Discussion Responses Written on Board	3	0
Group Models	1	0

Initial Models	3	0
Initial & Final Student Models	0	15

Along with a change in what they analyzed, PTs also seemed to focus more on assessing development as opposed to final achievement. Thus, they tended to compare pre-post measures, often student drawn models that were completed before and after instruction. Further, many (thirteen out of sixteen) of the PTs used their analysis of the initial models to guide their instructional strategy. For example, in the final reflection paper, Anna analyzed the initial student models on hemophilia, a genetic disorder. In her initial analysis she commented, “There was no connection to proteins or a lack thereof, with hemophilia, or even with genes or DNA in general.” After her analysis of the student models, Anna commented “Based on the analysis of the naïve models, I have designed a worksheet to help the students with the three main points that they are missing in their models.” She went on to describe at length what her worksheet entailed and planned to have the students complete the worksheet during the lesson. After completion of this worksheet, the students drew their final models. Anna then analyzed the final models and commented on the student growth in understanding stating:

> “In their revised models, many of the students drew double helix shapes with little dots on the DNA for the normal parent, and a double helix shape missing the dots for the child with hemophilia. They were able to discuss what clotting factors [proteins] were missing due to the difference in the DNA.”

In this example, Anna’s comments highlight growth in student understanding. Initially, she identified that the students were unable to see the relationship in the relevant biological mechanism (clotting factors in this case); however, their final models clearly connected these ideas and provided more complete mechanistic accounts.

Similarly, Clare analyzed her students' initial models on a lesson on cellular respiration, specifically the role of oxygen in the body. Based on her analysis of the initial models, she wrote:

> "The two main themes seen [in the models] were oxygen is used to push blood through the body and oxygen is used to release energy from food. Although as seen [in the models] these ideas occur frequently, but they [the students] do not relate to oxygen, food, and energy in the body."

Clare concluded that the students were not making the connection between aspects such as food, oxygen, and energy. She decided that the students needed more evidence to make this connection so she had her students design experiments with the hope that the data they collected would allow them to see the interconnectedness of these three components. Clare then had her students write a paragraph on how the results from the experiment could influence their initial models. She commented "After reading through them [the paragraphs] I could see that many were on their way but more evidence needed to be given to solidify that oxygen is helping to release energy from our food."

From here, Clare then had her students engage in three other activities that she designed with the hope that the data they collected could be used as more evidence in their revised models. After her analysis of the final models, Clare stated "23 out of 27 students thought that oxygen is being used to release energy from our food, which is what I had wanted them to grasp". In this example, Clare was constantly assessing the students for understanding and based on her assessment she designed her instructional activities accordingly. Anna and Clare's approach of analyzing initial models and designing curriculum material to build on these models was commonly observed in the final reflection paper. Approximately 80% of PTs adjusted their lessons based on analysis of the initial models.

Another change we observed was that initially the PTs viewed student models to be informative about student understandings of scientific practices but not necessarily their understanding of the content. In the teaching experiment reflection, in which we asked the PTs to comment on student understanding as it related to scientific content and scientific practice, many of the PTs would only discuss content as it related to rote/recall prompts on worksheets or lab write-ups and they would only comment on scientific practices in regards to models. Further, many of the PTs who did not analyze models did not provide a thorough analysis of what the students learned about scientific practices. For example, Nina analyzed worksheets on the structure of DNA in her teaching experiment paper. When commenting on content she provided clear descriptions and provided evidence from the worksheet of what her students did or did not understand. However, when remarking on the students' knowledge of scientific practices, she noted "The students did not want to answer anything further then they had to. Explanations of why they choose one option over another was something they avoided at all costs. " In Nina's case, she did not provide any evidence from the artifact (worksheet) to support her claim about the students' understanding of scientific practices. Similarly, the analyses of the PTs who did not analyze models lacked evidence based justifications for their claims about students' understanding in regard to scientific practices.

The PTs who did analyze models in the teaching experiment paper also tended to analyze another artifact. For example, Bani chose to analyze a worksheet on bacteria and the students' initial models. In her analysis of student understanding as it related to content Bani stated, "Based on the analysis of the worksheet, the students understood that bacteria are everywhere because about 10 students said that after touching everything you touch your face or cell phone therefore that object has more bacteria on it." Further, in her analysis of student understanding as it related to scientific practices Bani remarked:

> "In the students' models, half of the students understood that labels are important when modeling; however, they [the students] did understand to justify their claims. None of the students just gave me one word answers- they justified why they believed what they believed."

Bani viewed the worksheets as a means to assess content while the models were a means to assess scientific practices, she did not attempt to analyze content understandings based on the models.

As the teacher education program progressed, many of the PTs began to see the multidimensional nature of models in that they could be a tool to assess both content and scientific practices. For example, in the final reflection paper, Nina chose to analyze the initial and final models her students constructed on the topic of osmosis. In her analysis, she wrote:

> "All of the students were able to tell me that the solution used was a hypertonic solution. Most of the students told me that the cell membrane shrunk and a few wrote that it only happens in plants. Unfortunately, many of the students did not

> provide justifications in their models or provide detailed mechanisms of how/why there was water loss in their models."

In this example, Nina was able to assess students both in terms of content (i.e., cell membrane shrinks in a hypertonic solution) and scientific practices (i.e., mechanism and justifications). Similarly, in Bani's final reflection paper, she chose to analyze the initial and final models on the topic of cellular respiration. Based on her analysis, Bani commented:

> "About 13 students out of the 20 were on the right track about how glucose turns to fat. However, out of the five groups, three of the groups were able to interpret the data and understand that glucose breaks down to pyruvate and then converted to Acetyl coA. The other two groups just talked about one piece of the data and ignored the rest of the statements given to them. They also just summarized the models and did not give any explanation."

Here, Bani assessed her students' understanding in terms of content (in this case how glucose turns into a fat) as well as scientific practices (interpretation of data and existence of explanations). We found that 94% (fifteen out of the sixteen) of PTs assessed student understanding in terms of content and scientific practices based on their analyses of student models in their final reflection papers (which had the same instructions as the previous reflection papers); thus, the PTs began to view models as a tool that could be used to assess the interconnectedness of scientific content and practice.

3.5 Discussion

The research on how PTs use assessments, and in particular, how they make sense of student understanding by analyzing student work is somewhat limited (Windschitl, Thompson, & Braaten, 2009). Therefore, in this investigation, we examined how PTs interpreted student thinking in static artifacts as well as how they analyzed written work for student understanding. In general, we found a shift in the way the PTs assessed student ideas in regard to scientific content and practices. It seemed that the PTs began to assess students on the interconnectedness of their ideas in terms of both scientific content and scientific practices. The PTs tended to move away from the perspective of “get it or don’t get it” (Otero, 2006) towards a more interpretive stance. Crespo (2000) argued that novice teachers tend to focus on the correctness of ideas rather than the meaning of the ideas. However, in this investigation, we observed a shift toward the more interpretive orientation. This slight shift may be a result of activities the PTs engaged in throughout the program. For example, the PTs were required to analyze student responses to assess for student understanding. As the PTs had more practice with assessing student responses, they may have developed a more sophisticated perspective on how students learn. It seems that PTs can attend to student thinking under certain conditions in real time (i.e., Levin, Hammer, Coffey, 2009) and when analyzing student work.

In addition, we observed that as the PTs began to be more nuanced in their assessment of student ideas there was a shift toward construction of more sophisticated curriculum material. Thus, construction of higher order thinking artifacts corresponded to a more interpretive and sophisticated approach to analyzing student thinking, such as the construction of data tables to highlight student ideas. Based on our findings, it seems that the construction of curriculum material should be a central focus in teacher education programs because how they are constructed, in terms of the questions that are being asked, potentially impacts how teachers assess for student understanding. Other researchers, such as Ball & Cohen (1996) and Brown & Edelson (2003), also advocate for the importance of curriculum material construction since it serves an important role in the classroom by influencing teachers' pedagogical decisions, shaping teachers' design of their planned curriculum, and serving as a source of teachers' learning.

Another goal of our research was to examine how PTs justified student understanding. Overall, we found that as the program progressed the PTs began to implement a more sophisticated justification scheme. This is encouraging because the PTs are seeing the importance of providing evidence for how they interpret student learning. Given the developmental approach taken by the *Framework for K-12 science education: Practices, crosscutting concepts, and core ideas,* the *Next Generation Science Standards,* along with the focus on progression of ideas across grades and the movement toward evidence-based instruction and decision making, a nuanced understanding of student thinking is better aligned with this approach than a binary view of student understanding. In addition, the nuanced approach for understanding is also important with the currently changing standards in which teachers will be evaluated. In many states nationwide, teachers are now going to be evaluated on student growth in understanding as well as to provide evidence-based instruction. Evaluating students from a developmental approach will be an essential skill that teachers will need to work on with the construction of rubrics to assess student learning as well as be able to construct appropriate instructional strategies to move toward more normative understandings.

Thereby, these types of formative assessments will continue to be essential components of instruction (Black & William, 1998).

Finally, our last goal of this investigation was to explore the types of artifacts the PTs selected to analyze. Initially, we found that the PTs selected rote/recall prompts on worksheets to analyze but throughout the program they shifted in their selection and began choosing initial and final student models (models that were drawn before and after instruction). It seemed that their selection of artifacts was more purposeful and productive in that they chose these artifacts as a “pre-post” to measure the growth in student understanding. Even more compelling is that many of the PTs began to use their analysis of the student initial models. This is encouraging given research that has shown that PTs do not know what to do with students ideas once they have been surfaced (Jacobs et. al, 2010; Davis, 2006). However, in our study, it seemed that the PTs were able to suggest instructional strategies to help alleviate some of the conceptions the students had based on their analyses of the students’ models. One plausible explanation for this difference may be the focus on analyzing static student artifacts since previous research focused on videotaped teaching episodes and interviews (i.e., Zembal-Saul et al., 2000; Mellado, 1998).

We also observed that PTs views of artifacts began to change. Initially, PTs felt they could only assess scientific practices in models and content in other artifacts such as worksheets or lab write- ups. However, throughout the program, the PTs began to see the multidimensional nature of artifacts in that they could be a measure to assess both content and scientific practice. It seemed that as the program progressed, the PTs overall views of artifacts and what they could tell them in regard to student thinking began to be more comprehensive and not limited by the artifact. Although we did not stress how to select artifacts in our methods courses, this could be explained in that as the PTs began to analyze student work more frequently they began to see the interconnectedness of the material and thereby began to use one artifact to analyze both understanding (scientific practices and content).

3.6 Implications and Limitations

There is very limited research on how engaging in analyzing written work impacts PTs assessment of student ideas. Further, many studies argued that PTs' ability to interpret student thinking is less developed than experienced teachers (Morris, 2006). In our investigation, we provided some insight as to how PTs interpret student understanding. Our results indicated that PTs are capable of assessing student ideas given static student artifacts. Further, it seemed that as the PTs had more experience with analyzing student artifacts, they began to use their assessments to inform their subsequent instruction during their student teaching practicum. Our results are encouraging to teacher education programs because these findings suggest that a key role in any program should be engaging PTs in these tasks of analyzing student work as part of the reflection is productive. By analyzing their students' artifacts, they can potentially provide more informative instructional moves that correspond to their students' learning patterns, as well as develop deeper interpretations of student thinking. In addition, we feel that teacher education program should provide PTs with opportunities to observe how construction of student artifacts impact learning goals. By engaging PTs with experiences to examine prompts or instructions in student artifacts the PTs will be able to gleam how the phrasing of questions effect student thinking and understanding.

We would also like to discuss some of the limitations of this study. This investigation examined one cohort of teachers, thus our sample size was relatively small; thereby, impacting the results of our study. We feel that examining a larger sample size would be beneficial to explore whether there are other ways that PTs interpret student thinking. Further, although our results suggested that there was a shift towards assessing students in more sophisticated and nuanced ways, the scope of our investigation did not follow the PTs into their in-service teaching years. We feel that further research should be conducted to explore these PTs into their early teaching years to examine any changes to their assessment of student thinking.

Chapter 4:

Exploring preservice teachers development of awareness of student thinking

Abstract

Various reports have emphasized the need to engage students with the practices of scientific inquiry, specifically model-based inquiry in which students develop models to explain phenomena. A key factor in implementing this practice is the ability for teachers to attend and interpret student learning to guide instructional design. Attending to students' thinking is not a new idea; however, it is a major obstacle for preservice teachers (PTs). The construct of noticing, which attempts to explain attending behavior, is the ability to notice and interpret significant interactions in the classroom. However, there are several challenges associated with helping PTs develop the skill of noticing including the cognitive load involved in attending to the messy contexts of the real classroom environment and the logistics involved in obtaining videos of PT instruction. To circumvent this problem, teacher educators can focus on the precursors of noticing including framing and developing an awareness of student thinking; therefore, our investigation explores how the construct of developing an awareness of student thinking changes over the course of a two year teacher education program by analyzing written student artifacts. Despite an increased focus on how teachers attend to student thinking in recent years, little is known about the development of this behavior (van Es & Sherin, 2010). Further, we explored how the task structure of various assignments completed throughout the teacher education program impacted the PTs' attention to student thinking.

4.1 Introduction

Over the past thirty years, several documents have stressed the importance of engaging students with the epistemology and practices of scientific inquiry (National Research Council [NRC], 1996, 2007, 2011). The recent NRC report (2011) identifies eight inquiry practices that are essential elements of the K-12 science and engineering curriculum. These practices include asking questions, developing and using models, and planning and carrying out investigations. Further, the *Next Generation Science Standards* entail more student centered instruction as well as working with students' ideas in their development of science knowledge.

Attending to student thinking is not a novel idea, and has been a core aspect of many pedagogical content knowledge (PCK) models. For example, both Grossman's (1990) and Magnusson's et al.'s (1999) models of PCK account for the importance of teacher's attention to and knowledge of student thinking in the domain. Despite the need and benefits of attending to student thinking, this practice is challenging for experienced teachers and is even more difficult for preservice teachers (PTs) (Chamberlin, 2005). For example, Jacobs et al. (2010) found that even after teachers identified what students did not understand, they still struggled with suggesting instructional practices to ameliorate these misunderstandings no matter how much experience they had. Similarly, Tabachnik and Zeichner (1999) work with PTs showed that while PTs were interested in uncovering their students' understandings of particular concepts in science; they did not take this information into consideration when designing their lessons. Moreover, even when PTs recognized that learners have prior knowledge they usually do not address these ideas in their teaching practices (Friedrichsen, Abell, Pareja, Brown, Lankford, &

Volkmann, 2009). It is even more challenging for PTs to attend to student ideas in the moments of instruction since there are so many interactions occurring at any given point and time in the class. Given these obstacles we chose to focus our investigation on how PTs attention to student thinking, when analyzing static student artifacts, developed over the course of a two-year teacher education program. We chose to evaluate how PTs attended to student thinking in a non-real time classroom setting in order to obtain a better understanding of how PTs addressed student ideas without the dynamic nature of classroom instructions. In addition, we examined how the task structure of various assignments completed throughout the teacher education program impacted the PTs' attention to student thinking to highlight how prompts or instructions of assignments impacted attention to student ideas. The next section of this paper will present the theoretical framework of noticing, which is attending and responding to student thinking in the moments of instruction. However, given that the focus of our investigation is attending to student ideas in static student artifacts, we will then present a precursor to noticing, which we termed *developing an awareness of student thinking.*

4.2 Theoretical Framework

In every profession, experts have the ability to interpret events in their domain of expertise. Goodwin (1994) termed this ability professional vision. For example, a detective's professional vision allows him to make sense of a crime scene and an architect's professional vision allows the architect to recognize key features in the design of buildings (Goodwin, 1994). Regardless of the context of the profession, there are three necessary practices- coding, highlighting, and the production and articulation of material representation that are part of professional vision. Goodwin defines these practices as follows:

- "coding which transforms phenomena observed in a specific setting in the objects of knowledge that animate the discourse of a profession"
- "highlighting, which makes specific phenomena in a complex perceptual field salient by marking them in the same fashion"
- "reification, or producing and articulating material representations" (1994, p.606).

For example, an archeologist's professional vision involves the practice of coding by developing schemas for the identification of different types of soils based on their color, texture, and consistency. An archeologist's professional vision involves the practice of highlighting the color patterns in the soil to differentiate where traces of human activity occurred such as where an ancient house may have been located. Finally, an archeologist's professional vision involves the practice of articulating material representations by taking the information gathered from excavation sites and constructing profiles of the various soil layers based on the information obtained.

Although Goodwin's work did not specifically focus on teaching, others have used the construct of professional vision to describe teaching practice. van Es and Sherin (2002) developed the framework of "noticing" based on Goodwin's notion of professional vision. Similar to the three practices noted by Goodwin, teachers' ability to notice consists of three professional skills: (a) identifying what is important, (b) making connections between the specifics of classroom interactions, and (c) using what one knows about the context to reason about the classroom situation.

The first aspect of noticing, identifying what is important in a teaching situation, refers to the ability of the teacher to select what they will attend and respond to in the class. Because there are so many different things going on in a classroom at any given point, the teacher must decide what is important and use this information to guide their instruction. For example, Leinhardt, Putnam, Stein, and Baxter (1991) found that experienced teachers have “check points” and use these “check points” to judge how the lesson is going and decide how to proceed. An example check point is the teacher knowing to assess students’ understanding of the steps of the scientific method before asking them to design a lesson an experiment using the scientific method.

The second aspect of noticing, making connections between specific events and broader principles for teaching and learning, refers to the teacher’s ability to determine how events in the classroom are connected to student understanding (van Es & Sherin, 2002). For example, when analyzing a video of a math lesson, expert teachers described the segment in terms of issues related to teaching and learning such as noticing a student having difficulty with a particular math problem and attributing that difficulty to an underlying misunderstanding of place value. In contrast, novice teachers tended to provide literal descriptions of what they observed in the video- taped lesson and rarely make the connection of how events they observe are related to student understanding.

Finally, the third component of noticing, using what one knows about the context to reason about the situation, refers to teachers noticing classroom interactions (e.g., student ideas) and how they are tied to the specific context in which one teaches. Thus, teachers must use their knowledge of the subject matter and knowledge of how students think about that subject matter to reason about events as they unfold (van Es & Sherin, 2002).

For example, teachers of science will more accurately reason about classroom interactions in a science classroom than interactions in a literature or mathematics classroom.

Engaging in these practices of noticing enhances student learning because teachers' pay more attention to student thinking (Black & Williams, 1998). However, the development of these practices can be challenging since their application happens in a manner that is fleeting and distributed through the moments of instruction (Sherin et al., 2008). This fleeting, complex, and dynamic nature of noticing poses challenges for teacher educators striving to help PTs develop these practices. It is often difficult to help PTs notice in real time due to the cognitive load involved in attending to the messy contexts of real classroom interactions as well as the logistics involved in obtaining videos of PT's instruction. We suggest that one way to circumvent these obstacles is to focus on the development of precursors to noticing, what we term an *awareness of student thinking*. We use the phrase developing an awareness of student thinking to denote attending to students' thinking as it is manifested in static artifacts of student work. Specifically: (a) identifying evidence of student thinking in written artifacts; (b) interpreting this evidence in terms of how it connects to learning; and (c) deciding how to respond to their interpretation of students' understanding, through hypothetical future instructional moves. In this study, we investigated how the PTs' practices of developing an awareness of student thinking advanced over the course of a two-year teacher education program.

In addition to how these skills grew and developed throughout the program, we were also interested in uncovering whether the task structure of assignments completed throughout the program impacted the PTs' attention to student thinking. In mathematics education, the nature of the task was shown to influence how students think and learn (Henningsen & Stein, 1997); thus, we wanted to explore how task structures (i.e., prompts, instructions, directions) facilitated (or not) the PTs' attention to student ideas. Thus, we will be able to better adapt and modify the essential pedagogical skills teacher educators discuss in methods courses. Our research questions are:

1. In what ways does PTs awareness of student thinking develop over the course of a teacher education program?
2. How does task structure affect the development of awareness of student thinking?

In addition to investigating how PTs attend to student thinking, we wanted to further focus attention to student thinking around core aspects of science learning, specifically modeling. Scientific models are representations that attempt to explain natural phenomena. Scientists create models in the form of analogies, conceptual drawings, diagrams, maps, and computer simulations as a means of describing and understanding the organization and behavior of natural systems (Windschitl & Thompson, 2006).

We chose to focus on the practices of modeling because of the centrality of modeling in science (Longino, 2002; Giere, 2004) and consequently should have a central role in the science classroom (Lehrer & Schauble, 2006; Grosslight, Unger, Jay, & Smith, 1991; Snir, Smith, & Grosslight, 1988). Further, model- based inquiry instruction involves students developing models in the form of text, diagrams, formulas, etc. that elucidate and explain the phenomenon in question, and then testing and revising these models based on evidence. Engagement in model-based inquiry encourages students express their understandings, share, and argue about their ideas (NRC, 2011). Consequently, fostering model-based inquiry learning entails a shift towards more student-centered classrooms in which students construct their own understandings of scientific phenomena (NRC, 2000; 2007).

A key factor in implementing model-based inquiry teaching effectively is the ability to attend to and interpret student ideas and to use such interpretations to guide instructional design (Hammer, 2000; van Zee & Minstrell, 1997; NRC, 1996; AAAS, 1993), which is a central component of both PCK models. To study how PTs attended to student thinking, we analyzed responses to an interview task in which the teachers were asked to evaluate student models. We chose to analyze the teachers' evaluation of student models because other researchers, such as Jacobs et al. (2010) and Kazemi & Franke (2004), used student work because they felt that student work could help teacher develop a deeper understanding and interpretation of students' thinking.

4.3 Methods

4.3.1 Study Context

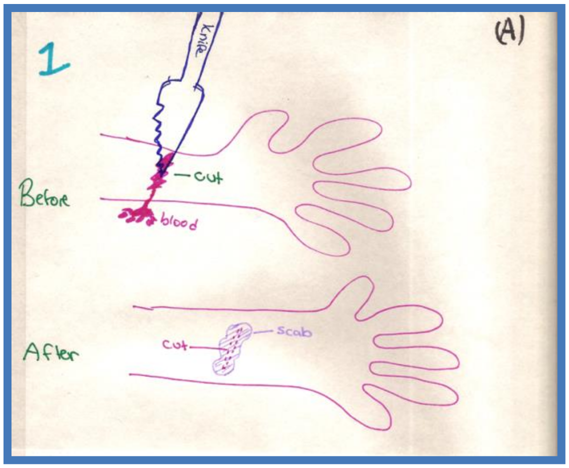
This study was conducted in the context of a two-year Ed.M. certification program for secondary biology teachers at a large public university in the North East (see Etkina, 2005 for more details about the program). There were fifteen PTs enrolled in the program. Four of the PTs were males and eleven were female. All of the PTs were Caucasian except one who was of Asian descent. All of the PTs' undergraduate degrees were in the biological sciences with nine having biology degrees, three having animal science degrees, three having environmental science degrees, and one having a molecular biology degree.

The program entailed a variety of coursework about: learning, diversity, and assessment. The program also included four life science specific methods courses that were taken in sequence (including a seminar that accompanied student teaching). These methods courses were geared towards helping PTs develop their knowledge and practices of model-based inquiry teaching. The first course, *Methods I*, focused on developing PTs understanding of the nature of scientific inquiry and the central role of modeling in the development of scientific knowledge. *Methods II*, the second course was essentially a design course in which the PTs worked in groups to design an extended inquiry-based unit as well as implemented a short model-based inquiry lesson. *Methods III*, which accompanied the teaching internship, focused on the implementation of model-based inquiry instruction as well as reflecting on their instructional methods. The majority of the PTs completed their student teaching internship at suburban, public high schools in the North East while one PT completed the requirement at an inner-city, public high school in the North East. Finally, the fourth course, *Methods IV*, engaged teachers in action research using data collected during the teaching internship. All courses, especially the latter two, included an emphasis on student thinking, and engaged PTs in analysis of student work.

4.3.2 Data Collected

In this investigation, we used four different data sources to address our research questions. To address the first research question, we analyzed the clinical interviews that were conducted at the end of each methods course. To address the second research question, we analyzed the teaching experiment interviews and analyses that was completed during *Methods II*, the VNOS (views on the nature of science) survey that was completed during *Methods III,* and the student transcript analysis that was completed during *Methods IV.* Each assignment will be discussed in more depth below.

PTs Clinical Interviews: As part of the coursework the PTs participated in clinical interviews at the end of each of the four methods course. A faculty member and trained graduate students conducted the interviews. Although somewhat different protocols were used in each set of clinical interviews, there was a common student-model critique task, which is the task analyzed in this investigation. In this task the PTs were presented with three “student models” explaining how a cut heals (cellular division) or why ice floats (density); the two versions were used for counterbalancing purposes. The research team created the “student models” to closely mimic the kinds of ideas commonly expressed by students as surmised from the research literature. We engineered these models to vary in terms of level of details, scientific accuracy of explanation, use of evidence (in the form of prior knowledge used in the model explanation) and justification of how the evidence relates to the explanation provided in the model. The models consisted of a drawing with an explanation written underneath. There were six models in total (Appendix A and Appendix B). Below is one of the “student models” used in the interview.



When you get a cut after a week a scab forms on it. I know this because I saw pictures of scabs and when I look with a microscope you can see the scabs.

Figure 4.1: Sample of student model from the "how a cut heals" set.

The PTs were then asked to identify (a) good aspects of the models, (b) problematic aspects of the models, (c) description of their next instructional move when told these were naïve models (i.e., if students initially drew these models without any prior instruction), and (d) description of their next instructional move when told these were revised final models (i.e., students drew these models after instruction about the topic). Interviews lasted 30-45 minutes and were videotaped and later transcribed verbatim.

Teaching Experiment Interviews. The focus of *Methods II* was on designing extended inquiry units. As part of the design process, the PTs were required to interview at least three participants on an assigned biological topic in order to assess prior knowledge. The participants had to have taken either high school or college biology. The goal of this assignment was to use the participants' responses to aid in the development of an inquiry unit on the given biological concept. After designing and conducting the interviews, the PTs were required to analyze the participants' responses to find patterns (similarities and differences in the responses) as well as to use the participants' statements in the form of quotes to support their analyses

VNOS (Views on the Nature of Science) Survey: This assignment was completed during *Methods III.* We wanted to provide the PTs' with opportunities to work with student responses in order to come up with nuanced analyses of student thinking. For this assignment each PT was required to implement a "views on the nature of science" (VNOS) questionnaire during their student teaching internship to elucidate students' views on science. The PTs then collectively developed a hierarchical coding scheme (eight different categories to the coding scheme) to analyze the student responses to the questionnaire. The PTs were required to analyze one of the questions using the agreed upon coding scheme. Based on their analysis, the PTs were then asked to explain what activities they would do in class to move the students from lower to higher categories.

Individual Student Transcript Analysis. This assignment was completed during *Methods IV.* We wanted to again provide the PTs' with other opportunities to work with student ideas to develop nuanced analyses. For this assignment, the PTs were given a transcript of a student interview (the transcript was data the professor of the course had collected as part of a research project). The PTs were asked to analyze the student responses from the interview to answer the question *how does the student conceive of genes, proteins, chromosomes, traits, and the connection between these entities.*

.4.3.3 Data Analysis

PTs Interviews. We initially blinded the interview tasks regarding PT and course. We then read through the interviews and developed analytic memos to capture what PTs noticed in the models, such as the use of evidence and justification and the accuracy of the content (to name a few). Each coder created separate analytic memos. We then reviewed each analytic memo for similarities and constructed one analytic memo that was comprised of the salient points from the individually constructed memos. Subsequently, we identified all of the possible factors that could be mentioned in the model evaluations based on how we engineered these models. Table 4.1 describes the different factors that were engineered into the models.

Table 4.1: Factors engineered into scientific models

Categories	**Description of Category**
Grain Size	The organization level at which the models were drawn- molecular, cellular.
Temporal Sequence	Model showing change over time- often represented as "before" and "after" images.
Mechanism	Explanation of what occurs- goes beyond process. Explains how various components fit together.
Labeling	Different components of the models were labeled, such as water molecules, skin cells, etc.
Extraneous Information	Information that did not serve a purpose in the model, such as smiley faces when the cut healed.
Evidence in Explanation	Evidence or data in the explanation, such as prior knowledge or experiment previously performed, such as "Model #3's explanation is good since it references the student's prior knowledge."
Justification in Explanation	Statement about how the evidence supports the claim in the explanation, such as "Model #2 shows temperature differences and it also provides a justification, in this case water properties."
Clarity in Model Representation	Components such as color coding.
Accuracy of Content in Model	Models and explanations had varying degrees of correctness, such as "Model #3 understands that molecules stick together but they don't understand why water floats."

Using the analytic memos and table, we analyzed the first two questions of the interview task in which the PTs were asked to identify the good and problematic aspects of the models. A comment was coded as *attending* if it related to a feature that was explicit in the models. For example, a PT mentioning the models had a before and after would be coded as “attending- temporal sequence” since the models were clearly labeled before and after. A comment was coded as *interpreting* if it related to a feature that was not explicit in the model. For example, a PT mentioning that the explanations are supported with evidence would be coded as “interpreting-use of evidence in explanation” since the PT decided what counts as evidence, which was not explicitly labeled as evidence in the models.

All of the features that were engineered into the models could be coded as either *attending* or *interpreting* depending upon whether the PTs addressed how these features related to the students’ overall learning process. For example, a comment such as “the models have a before and after” would be coded as “attending- temporal sequence” since it related to an explicit feature of the model with no further elaboration. However, a comment such as “there is a before and after in the model so the student understands that there is a process or sequence that needs to occur in order to heal” would be coded as “interpreting- temporal sequence” since the PT elaborated how the before and after related to student understanding. All of the PTs’ comments related to some feature we had engineered into the models.

To analyze how PTs planned their hypothetical next instructional move, we coded their responses to the question, *what would you do in class the next day if these were naïve models*. Our goal was to determine if the responses were connected to their critique of the models along with the specificity and viability (i.e., were the lessons easily executed) of the suggested solutions. We coded their responses as low, medium, or high. A "low" code response was vague and not connected to their evaluation of the model. For example, when PTs suggested that the students be provided with evidence but use of evidence, or lack thereof, was not raised as a problem in their critique. A "medium" code response was vague but connected to the evaluation. For example, when PTs suggested that the models lacked evidence in their evaluation and recommended providing data to the students. Although a suggestion was provided, it is still unclear how the PT will provide data- will they have the students conduct an experiment, will they present their students with a study conducted by scientists. The use of "provide data" is too open to interpretation. A "high" code response was detailed, "doable", and connected to the evaluation. For example, when PTs suggested that the models were not drawn at the cellular level and recommended performing a microscope experiment in which the students could observe the different stages of cellular division.

We analyzed the last question of the interview task, *what would you do in class the next day if these were revised models,* by creating a comprehensive list of the strategies the PTs said they would employ. We similarly coded responses to determine if the responses were connected to their critique of the models along with the specificity and viability of the suggested solutions. We chose not to analyze this last question with the codes of low, medium, and high because often the PTs mentioned doing the "same thing as they would do if these were naïve models". We compared the analyses as it related to the content of the models and noted any observed differences for the responses to naïve and revised models.

In order to determine any developmental changes that occurred throughout the course of the teacher education program, we denoted the interview responses that were conducted the first year of the program as the "pre" data and the interviews conducted the second year of the program as the "post" data. We compared the responses for the pre/post interviews and noted any differences. Further, we also wanted to see if there was a difference in the interview responses from the biological version and the physical science version; thus, we compared the responses of the different subject matter.

Teaching Experiment Interviews Analyses. We read through the analyses in their entirety. Our goal was to examine how PTs' attended, interpreted, or hypothetically responded in their analyses of the interviews. We identified what features of student thinking the PTs were able to attend and interpret (there was virtually no hypothetically responding). Using a constant comparative method (Glaser, 1964), we were able to categorize the interviews into different groups based on the skills the PTs employed- some PTs just attended to student thinking while other PTs attended and interpreted student thinking. We further explored how the PTs justified their analyses. A justification was coded as any rationale a PTs employed in their analyses.

VNOS Survey. We initially examined how the PTs categorized the student responses into the eight category coding schemes. We explored if there were any patterns in the categories (i.e., did most of the PTs place their students in one level of understanding over another, were there some categories that were never addressed). We then analyzed the PTs hypothetical responses. We created lists of the various follow-up lessons the PTs suggested. We examined how in depth the lessons were, how easily executable they were, as well as how connected the lessons were to their analyses of student understanding based on their coding schemes.

Individual Student Transcript Analysis. For this assignment, we followed a very similar protocol for our analyses as we had for the teaching experiment interview analysis. We explored how the skills of attending and interpreting (again there was virtually no hypothetical responding) student ideas was evident in the analyses. We examined what aspects of student understanding the PTs addressed as well as the various justifications the PTs employed in their analyses.

Trustworthiness. We employed several strategies to ensure trustworthiness of our analyses. We used peer-checks to enhance validity of our interpretations of the data. We provided thick descriptions of our methods as well as "raw" data in the form of numerous quotes to allow the reader to track and evaluate the evidentiary base of our claims. We established intercoder reliability by having two independent coders code half the data (reliability ranged between 95-97%); any disagreements were resolved and codes were adjusted to reflect the consensus.

4. 4 Results

4.4.1 In what ways does PTs awareness of student thinking develop over the course of a teacher education program?

Attending. Our analysis of the first two questions of the interview task allowed us to determine what aspects of students' thinking the PTs attended to. Table 4.2 below reveals the number of comments that involved attending to students thinking that were noted in relation to the categories of comments we identified. Recall, the categories in this table represent problems and deficiencies we engineered into the models, and we wanted to see what the PTs would comment on. The pre-responses corresponded to interviews conducted during the first year of the program, while the post-responses corresponded to interviews conducted during the second year of the program.

Table 4.2: Attending to student thinking comments coded for pre/post data.

Categories	**Pre**	**Post**
Labeling	16	15
Clarity in Model Representation	6	5
Temporal Sequence	3	4
Grain Size (cell/molecule or not)	0	0
Extraneous Information	0	0
Evidence in Explanation	0	0
Justification in Explanation	0	0
Mechanism- explanation of what occurs- goes beyond process	0	0
Accuracy of Content in Model	0	0

The analysis revealed that PTs tended to attend to and comment on superficial aspects of student thinking such as whether models were labeled and drawn clearly. Labeling and clarity of model representation were the most noted regardless of the subject matter of the models (cut healing or ice cubes). Further, there was no change in terms of the aspects the PTs attended to between the pre and post measures. The only other category that PTs attended to was the temporal sequence category.

Interpreting. Our analysis of the first two questions of the interview task also allowed us to determine what aspects of students' thinking the PTs interpreted. Interpreting refers to the ability to attend to student ideas and determine how that relates to the students' overall learning process. Interpreting referred to comments that evaluated an aspect of student thinking that was not explicit in the models. Table 4.3 below reveals the number of interpreting student thinking comments by category.

Table 4.3: Interpreting student thinking comments coded for pre/post data.

Categories	**Pre**	**Post**
Grain Size (cell/molecule or not)	23	25
Evidence in Explanation	20	22
Accuracy of Content in Model	16	19
Mechanism-explanation of what occurs- goes beyond process	16	11
Justification in Explanation	15	12
Extraneous Information	4	4
Temporal Sequence	0	0

Clarity in Model Representation	0	0
Labeling	0	0

The analyses of the first two questions of the interview task revealed that PTs tended to focus on the grain size of the explanation in the models, the use of evidence in the student models, and the accuracy of the content in the models. Comments that referred to the grain size of the model focused on the level that the models were drawn at (i.e., were the models at a cellular level or molecular level versus were the models giving the overall picture- skin or iceberg). For example, Nina commented “model #1 is a macro-image while models #2 and #3 are micro- level”. Nina is referring to the fact the first model shows a scab healing on skin (i.e. macro-level) while the second and third models show the cells healing (i.e. micro-level). Comments that referred to the use of evidence in the models focused on how the students employed evidence (i.e., data, experiments, prior knowledge) in their models. For example, Ava stated “model #3 is using prior knowledge as evidence to explain what is occurring.” Ava interprets evidence as “prior knowledge” and that is how she felt the student was supporting their reasoning in the models.

Overall, there was not much change over the course of the teacher education program. Upon comparing table 4.2 and table 4.3, it is evident; however, that PTs tended to provide more comments that could be coded as interpretive. There were many more interpretive comments as compared to attending comments (27 versus 94 in the pre data; 26 versus 93 in the post data). Additionally, we did not observe any differences between interpretive comments that related to a positive feature in the model or a negative in the model. However, when we compared the interpretive comments based on the subject matter of the models, we found that the PTs tended to focus on the accuracy of the content in the physical science models (almost twice as many comments) as compared to the biological models. This is somewhat surprising since the PTs were all biological science majors.

Hypothetically responding- naïve models. We next explored the PTs suggested hypothetical lessons after their analysis of the student models. We wanted to engage them in the authentic practice of evaluating student ideas and being able to address these ideas in follow up lessons. Thus, the second part of the analyses focused on the third question of the interview task in which the PTs were asked to propose hypothetical follow up lessons given these were naïve models (initial models prior to formal instruction). Our goal for this part of the analyses was to characterize the specificity and relevance of the hypothetical follow up lessons (i.e., were the follow up lessons connected to the PTs evaluations of the models) and the viability of these hypothetical lesson plans (i.e., were the suggested strategies sensible solutions to the problems noticed). Table 4.4 reveals our findings below. We coded responses based on how explicit and detailed they were (i.e., were their lessons feasible and executed) and the connection to the PTs' critique (i.e., does their lesson address aspects of student thinking they noted previously in their evaluation).

Table 4.4: Scores given to hypothetical follow up lessons in terms of connection to critique and specificity of the suggested strategy for pre and post data

	Low	Medium	High
Pre	12	13	7
Post	8	14	10

Our analyses revealed that initially the PTs tended to be vague in their suggested follow up lessons. However, over the course of the teacher education program, there seemed to be a shift towards instructional moves that were more detailed and easily executable as well as lessons that connected to the PTs' evaluation (63% of models were of medium or high quality in the pre data versus 75% in the post data). For example, this shift was evident in Clare's responses during the two interviews. In the pre interview, Clare responded that if these were naïve models, "I would start a discussion or ask probing questions and hopefully this would shed some light on the students that certain models aren't making sense." In this response, Clare is very vague in her lesson description (i.e., what probing questions would she ask? and how would this help students see gaps in their understanding?) and this lesson plan was not connected to her evaluation of the student models in which she stated the accuracy of the content of the model was incorrect. In the post interview conducted the second year of the program, Clare stated:

> "I would ask the students to explain their models so that I am sure they understand the question. I would then have the students contrast the different models and write reasons how they are different. I would bring in pictures of cuts at the microscopic level along with a progression of the healing process. After the discussion and showing the students the pictures, I would have the students go back and re-do their models."

In Clare's response she provided more specific details about the questions she would ask, what instructional moves she would make, and what resources she would bring to the classroom to help kids see the gaps in their knowledge. Her response was also connected to her evaluation in which she addressed the grain size issue of the models (i.e., providing students with cellular level pictures of a cut healing) and the lack of evidence in the models (i.e., providing students with pictures of the progression of cells healing).

Our comparison of responses in the "naïve" condition given the two types of models (cut and iceberg) that differ in subject matter is shown in Table 4.5.

Table 4.5: Scores given to hypothetical follow up lessons in terms of connection to critique and specificity of the suggested strategy for subject matter for pre and post data

	Low	Medium	High
Physical Science Models	7	13	12
Biological Models	13	14	5

This comparison revealed that PTs' follow up lessons for the physical science models tended to be more detailed and were more feasible. Further, the strategies the PTs suggested in their lesson plan for the physical science models were better aligned and more tightly linked to their critique of the models. In total there were six suggested strategies that were both specific and connected to the PTs' evaluations. For example, several PTs suggested comparing the volume of water at different phases (liquid versus solid) so that the students could witness that ice expands in cold temperatures. This suggestion was helpful since it helps rule out the model that stated that things shrink in the cold. Thus, the PTs seemed to be better able to diagnose the content inaccuracies in the given models and were subsequently able to come up with sensible teaching moves to address these issues.

Another suggested instructional move that was frequently mentioned by the PTs was to have students work with objects that had different densities to explore the impact of density as it relates to floating and sinking. Such an activity would be productive and relevant since several of the models suggest density but their definition of density was inaccurate. By allowing the students to experiment with objects of different densities, the students could get a better understanding of the concept.

In comparison, the biological models only had two solutions that were productive and connected to the PTs evaluation. Most of the suggestions for the biological models involved having the students discuss their models or having students work collaboratively with their models. These suggestions are not very detailed in that they do not provide a clear view of how the PT would accomplish these discussions or group work activities (i.e., what types of questions would the discussion entail, what would the students do while working in groups). Further, these responses were not connected to the PTs evaluations; they did not address any problematic aspects of student thinking that were evident in the models.

We also wanted to explore the nature and type of problems the PTs addressed in their follow up lessons, assuming that these were naïve models, and what aspects did they target in their follow up lessons. Overall, we found that regardless of time (i.e. pre/post) and subject matter of the models, the PTs tended to target one problem in their follow up lessons whether it was providing evidence, content, or grain size of the models (these were the most common). However, we noticed that PTs tended to target content in their follow up lessons for the physical science models while they targeted the grain size for the biological models. We feel that the difference in suggestions between the subject matter could be due to the fact that the PTs may have had more experience (in terms of labs and experiments) for the density context than for the cellular division context.

Hypothetically responding- final models. The last part of our analyses explored the response to the question, *what would you do in class the next day if these were revised models*. Similarly to our analyses of the naïve models-here we wanted to determine what the PTs were targeting in their follow up lessons, how many problems they were targeting, and how sensible were their suggested strategies. Overall, we found that the PTs tended to, again, target one problem and that they tended to focus on the same problem in the revised model as they did for the naïve model regardless of the time (pre/post) and subject matter of the models. For example, if the PTs initially suggested providing the students with data (in their follow up lessons given the models were naïve) than they would suggest providing the students with more data or different data when told these were revised models. Table 4.6 lists the different instructional strategies the PTs mentioned.

Table 4.6: Instructional strategies suggested for revised models

Instructional Strategy Suggested	**Number of Times Strategy was Suggested**
Go Back and Redo Lesson	18
Provide New or Different Evidence	7
Students Work in Groups to Revise Models	5
Change Prompt	2

Thus, overall, we found that the strategies suggested by the PTs in follow up lessons had minimal differences regardless of the time (pre/post) or subject matter of the models, with the most commonly noted strategy of "going back and redoing the lesson".

4.4.2 How does task structure affect the development of awareness of student thinking?

We next wanted to explore how the nature and structure of certain assignments that the PTs completed during various time points in the teacher education program facilitated (or not) attention to student thinking.

Task #1. The first assignment that we examined was completed during *Methods II.* For this assignment, the PTs were asked to create interview questions on a given biological topic, conduct an interview using these questions with at least three participants, and then analyze the interview responses. The goal of this assignment was to use the participants' responses to aid in the development of an inquiry unit on the given biological concept. We specifically asked the PTs to *analyze* the participants' responses in terms of student understanding not merely *summarize,* for each biological topic. We asked the PTs to find patterns in the participants' responses (similarities and differences) as well as to use quotes to support their analyses. The participants were selected by the PTs with the only requirement being that the participant had to have taken biology either in high school or college. Overall, we found that PTs analyses tended to be either: (a) attentive to and interpretive of student thinking (first two components of developing an awareness of student thinking) or (b) attentive to student thinking (only first component of developing an awareness of student thinking). The analyses that were attentive and interpretive of student thinking, which were the majority of the analyses (67%), had certain features.

The first feature was that the PTs provided student responses in the form of quotes and used the student responses to explain "what this was a case of". In this analyses, the

PTs were able to provide direct evidence to support their claims regarding the participants' understandings and ideas. For example, Eric wrote:

> "I asked the question *how parents pass traits to offspring.* I received responses like "traits are passed through chromosomes (student 2) and "egg and sperm are reproductive agents that pass chromosomes (student 1). Based on these responses I can conclude that the students do have a somewhat basic and generalized understanding of what chromosomes/genes do (terms are interchangeable) and that they are carried by sperm and egg which "may or may not be cells."

In this instance, Eric cited specific responses from the interviews and explained how the responses were indicative of the participants' understanding.

Another feature we noticed was that PTs analyses that were attentive and interpretive of student understanding referenced specific ideas that students knew or did not know 68 times. Of those, 74% of the comments suggested a deficit view and highlighted what students do not know. For example, Bani wrote "The students couldn't come up with the idea that proteins could provide physical characteristics." .

Only a handful of comments highlighted the "half-full" aspect of the students understanding. For example, Christine commented "The students did recognize that cells would divide when others got old or damaged. However, no participant mentioned mutation as a cause of cell reproduction." In contrast to Bani, Christine indicated what she believed the students did and did not understand about the topic of cellular division. The analyses that were attentive to student thinking but not interpretive of student understanding (only the first component of developing an awareness of student thinking) were simply just summaries of what the students said in their interview. Despite being asked to include student responses, these PTs did not provide direct evidence of student understanding in the form of quotes from student responses. It seemed that these PTs just repeated what the students stated in the interview with no real analysis.

Overall, it seemed that the majority of the PTs were able to provide a more thorough analysis of student ideas in the interview task. The PTs who used direct evidence in their analysis seemed to be more cognizant of what the students were saying and were able to use this evidence to justify their interpretation of student understanding. However, although we specifically asked the PTs to provide student responses, there were a handful of PTs who did not and their analyses were much more descriptive (mostly summaries with no analysis) in nature.

Task #2. The second assignment we analyzed was written during *Methods III.* For this assignment each PT was required to implement a "views on the nature of science" (VNOS) questionnaire during their student teaching internship. We wanted to give PTs' another opportunity to work with students responses in order to come up with nuanced analyses of student thinking. The PTs then collectively developed a hierarchical coding scheme (eight different categories to the coding scheme) to analyze the student responses to the questionnaire. The PTs were required to analyze one of the questions using the agreed upon coding scheme. Based on their analysis, the PTs were then asked to explain what activities they would do in class to move the students from lower to higher categories.

In our investigation of the PTs analyses, we found that all but one of the PTs coded each of the students' responses to fit in one of the eight levels of understanding. It seemed that all of the PTs interpreted the student responses to be categorized at only one level. Only one of the PTs commented that she felt that “five of her student responses could be categorized into two of the eight given categories.” It seemed that the PTs tended to view students’ knowledge to be one dimensional; thus being able to be categorized in one of the coding scheme categories and that the PTs were unable to view the multi-dimensional aspect of student learning from given responses.

We then asked the PTs to suggest an activity they could do in class to move the students from the lower categories of understanding to the higher categories of understanding. Overall, the majority (82%) of the PTs provided general activities with no real connection to their analyses. For example, Jake wrote “Give the students a selection of data and allow them to work in groups to come up with an answer.” In this case, Jake was not explicit in what type of data he could give them as well as what they would be doing in the group with this data. Moreover, his suggestion was not linked to his analyses of the VNOS survey since he did not mention why he chose to implement this activity. Most of the other PTs responded in a similar manner.

However, there were a handful of PTs who attempted to link their activities to their analysis. For example, Jackie commented:

> “To assist in progressing students’ knowledge from lower categories to higher categories, I think it is important for students to understand scientists do not just “think” differently” or “have different opinions”. Instead the students need to be aware of the practices scientists use and the extent of research and experiments they perform before an idea is an accepted theory in a scientific community.”

In this instance, Jackie used her analysis, which indicated that the majority of her students thought that scientists think differently and therefore come up with different opinions, to emphasize the fact that she needed to promote scientific communities in her classroom. Jackie further described activities, such as analyzing data or class discussions that she would do to promote this; however, similar to Jake and the other PTs, her activities are vague and were not easily executable.

Overall, it seemed that the majority of the PTs were unable to suggest viable activities that they would implement in their classes. Moreover, the activities suggested were not explicitly connected to the analyses of the student responses. It seemed as though there was a disconnect between what we asked the PTs do and what they actually did. Further, despite collectively developing the coding scheme categories to use in the analyses the PTs were unable to view the multi-dimensional nature of student responses. This is a very important skill to develop since many states nationwide are asking teachers to develop rubrics (similar to the coding schemes the PTs developed) to grade student work to be used to measure student growth. Further, after analyzing the student responses, the PTs were unable to provide a detailed activity that was linked to their overall analyses.

Task #3. The last assignment that we examined was written during *Methods IV*. For this assignment, the PTs were given a transcript of a student interview (the transcript was data the professor of the course had collected as part of a research project). The PTs were asked to analyze the student responses from the interview to answer the question *how does the student conceive of genes, proteins, chromosomes, traits, and the connection between these entities.* Our goal for this assignment was to give the PTs opportunities to work with student responses to develop nuanced and sophisticated analyses of student thinking.

Overall, we found very similar results as compared to task #1. Again, the PTs' responses tended to be either: (a) attentive and interpretive to student understanding (first two components of developing an awareness of student thinking) or (b) attentive to student understanding (first component of developing an awareness of student thinking). The analyses that were attentive and interpretive of student thinking, which were the majority of the analyses (92%), were comprised of certain features.

Similar to our results for task #1, we found that the PTs who were attentive and interpretive to student understanding provided direct evidence in their responses in the form of student quotes from the transcripts. However, unlike in task #1, we did not specifically ask the PTs to include quotes in their responses. Moreover, the PTs would then again use these responses to explain "what this was a case of". For example, Catherine wrote, "Meera [the student in the interview] states "and that and that would cause umm…different kinds of eyes of skin cells or that disease that we talked about." Catherine continued:

> "I think she is saying that genes are not working properly would cause us to have different skin color or different kinds of eyes, skin cells, or diseases. We can also garner from this statement that she understands in some way that proteins are expressed because they affect physical traits that we can see."

It seemed that the PTs would use the student responses and interpret exactly what their responses meant to support their analyses of student understanding. On the other hand, the PTs who did not provide responses (8%) were not very analytical in their responses, simply summarizing what the students said.

However, we did observe one difference in this analysis as compared to task #1. We found that there were roughly 52 comments that related to what students did or did not understanding. Forty of those comments highlighted the “half full” part of student understanding unlike in task #1 in which the majority of the comments specified lack of student understanding. The task structure of this assignment was much more specific in that we specifically asked the PTs what the students understood in regard to genes, proteins, etc. On the other hand in task #1, the PTs were told to analyze and find patterns in the student responses; thus, it seemed that more specific prompts facilitated more specific analyses in regard to student understanding.

4.5 Discussion

In this investigation, we first wanted to characterize the development of awareness of student thinking, specifically we wanted to explore the components of student thinking PTs attended, interpreted, and hypothetically responded to based on responses to a model critique interview task. Recall, awareness of student thinking is a precursor to noticing that does not occur in real time. We chose to focus on this precursor since it is often difficult to help PTs notice in real time due to the cognitive load involved in attending to the messy contexts of real classroom interactions as well as the logistics involved in obtaining videos of PT’s instruction.

Throughout the course of the teacher education program, we observed that there was very little change in the PTs’ development of awareness of student thinking. We did notice that the PTs tended to be more interpretive in their critiques of the student models. Many studies, such as van Es & Sherin (2002) and Morris (2006) found that PTs are descriptive when noticing student thinking- that is they are able to attend to student thinking by identifying what the student does or does not understand; however, they are unable to determine how the aspect of student thinking they attended to is connected to the students' learning. Our results suggested that when dealing with static student artifacts PTs are better able to be interpretive in their analyses of student thinking.

We also found that the PTs focused more on accuracy of content in the physical science models. This is a bit surprising since we would have expected them to be more critical of the biological context given that they were all biological science majors. Moreover, it was also interesting that the PTs discussed the content of the biological models. Their comments about how a cut heals related to either how cells divided or how cells stretched in order to heal. It seemed that many of the PTs' thinking about how a cut heals was not scientifically accurate since cuts heal by dividing, not stretching. Several research studies have shown that novice teachers hold a range of inaccurate scientific concepts (e.g. Ginns & Watters, 1995; Stofflett & Stoddart, 1994; Trumper, 2003), which we also observed here. However, on the other hand, the PTs were much more descriptive in their comments about the physical science models and focused on several different aspects of the content as it related to these models. In addition, the PTs responses to the physical science models were more scientifically accurate. However, regardless of the subject matter of the models, the PTs tended to only focus on one aspect (i.e., category) in the follow up lessons. These results are congruent with Davis's (2006) findings that PTs emphasized one to two aspects of teaching when reflecting on instruction.

Although we did not observe a significant change in what the PTs attended and interpreted in regards to student thinking, we did discover that the PTs hypothetical follow up lessons shifted towards being more specific and were better connected to their evaluation. Our results suggest that to some extent PTs are able to develop potential responses (follow-up lessons) that could help ameliorate some students' misunderstandings. They were more able to do this in regard to problems, such as the grain size of the model and the use of evidence in models as compared to problems, such as the justifications in the explanations. It seems that PTs may struggle with components of inquiry, such as justifications, and that could be why the PTs were unable to address this aspect in follow-up lessons. Windschitl (2004) also found that PTs struggled to support claims. However, it is encouraging that PTs were able to develop more specific lessons that promoted student understanding in some simple contexts like student work. These results suggest that PTs will hopefully be able to develop more specific instructional moves that address student ideas in real time classroom settings.

The second focus of our investigation was how task structure of various assignments completed throughout the teacher education program impacted the PTs development of awareness of student thinking. It seemed that the specificity of the prompts or the instructions of the task impacted what the PTs attended to in regard to student understanding. Thus, more specific prompts facilitated more specific attention to student ideas. Although there is a limited amount of research in this vein, others have researched how task structures in mathematics impact student learning. Researchers, such as Henningsen & Stein (1997) found that how the task is written influences student learning. Thus, it seems that in our investigation how the task was written could potentially impact how PTs develop an awareness of student thinking. We also found that the PTs who used student responses in the form of quotes tended to be more interpretive in their analyses of student ideas. It seemed that by using the students' responses the PTs were more cognizant of what the student was saying; thereby, impacting the PTs attention to student thinking.

4.6 Implications

Many studies have found that PTs struggle with the practices of noticing (e.g. Morris, 2006); however, previous research has not provided more nuanced accounts of how these skills are less developed in PTs. Our investigation hoped to provide a more nuanced description of what PTs do and do not notice and to what extent are they able to interpret what they notice and respond to it. This investigation highlights the areas in which PTs still need to improve in their development of awareness of student thinking, such as targeting more problems in their follow up lessons and interpreting more aspects of student thinking such as justifications in explanations. It is not surprising that PTs struggled with certain aspects of student thinking, specifically justifications, since other research has shown that PTs had difficulty with this component as well (Windschitl, 2004).

Overall, we found that all of the PTs developed more specific hypothetical follow-up lessons that were connected to their evaluation when analyzing student artifacts; however, studies that had novice teachers analyze videos of teaching to develop these skills had mixed results in that some of the novice teachers' analyses became more specific to their video analyses while the other novice teachers did not (van Es & Sherin, 2006). By having PTs engage in tasks, such as evaluating student models, may be a productive way to help them learn to attend, interpret, and plan responses in a simpler, less dynamic (and potentially overwhelming) context of student written work. While this context is simpler, it is still very much authentic to what teachers have to do.

Overall it seemed that the task structure of an assignment could influence attention to student ideas. Based on the results from this investigation, it seemed that the more specific the prompt in the task, the more specific the analyses of student understanding. We feel that teacher educators need to be more specific in writing the prompts in the assignments completed during the teacher education program. Thus, instead of asking PTs to *analyze responses for student understanding*, teacher educators need to ask specifically ask what they want the PTs to attend to such as *how do the students conceive of X, Y, and Z.* Writing more specific prompts could potentially influence more attention to student thinking.

Chapter 5: Conclusion

5.1 General Discussion

In recent decades, numerous reports have called for the need to engage students in the epistemology and practices of scientific inquiry (i.e., NRC, 2011). However, this is a major obstacle given the fact that teachers have not had much experience with scientific inquiry either in their teacher education programs or their own experiences as students (Crawford & Cullin, 2004; Harrison, 2001;Justi & van Driel, 2005; Justi & Gilbert, 2002; Windschitl & Thompson, 2006). In particular teachers struggle to make sense of student ideas and steer their development. Researchers, such as van Es and Sherin, have explored how teachers account for student understanding by studying a construct they coined "noticing". However, developing the skills of noticing can be challenging since they happen in a manner that is fleeting and distributed through the moments of instruction (Sherin et al., 2008). Therefore, one way to circumvent this obstacle is to focus on the development of precursors to noticing. In in this dissertation, I investigated the precursors to noticing, which I termed *developing an awareness of student thinking*. Specifically I explored the research question *how does developing an awareness of student thinking change over the course of a teacher education program.*

Chapter 2 examined how the first component of *developing an awareness of student thinking* changed over time. In this investigation, I explored *framing.* Frames are the lenses of analyses PTs employed in their reflection paper. I found that PTs employed frames with varying degrees of attention to student ideas. Initially, the majority of the PTs employed the *engagement* frame which focused on student interest and participation. However, as the teacher education program progressed, there was a slight shift towards using frames that were more attentive to student understanding, such as *scientific* *practices- students,* which focused on students' actions while implementing scientific inquiry practices. It seemed that as the PTs gained more experience working with students in the classroom through their teaching internships, they began to focus less on themselves as teachers and more on students' learning (Berliner et al., 1988). Moreover, I found that the PTs who employed more student centered frames began to be much more elaborate and detailed in their description of student learning. For example, in later reflections the PTs became more nuanced and explicit about *the ways in which* the students had difficulty with scientific practices. One implication of this work suggested that teacher education programs should engage PTs in reflective practices. Engagement in reflective practices could be one way of shifting attention from themselves towards students and their ideas. In addition, engagement in reflective practices could promote PTs to be more interpretive of student thinking, an essential skill they will need in their future teaching career.

The next investigation I conducted examined the second component of *developing an awareness of student thinking,* specifically interpreting student understanding. Therefore, the focus of chapter 3 was to evaluate how PTs began to assess student learning for understanding as it related to scientific content and scientific practices in static student artifacts. My results indicated that the PTs began to see the interconnectedness of assessing scientific content and scientific practices rather than viewing them as separate entities. Further, I found that PTs began to focus more on assessing development as opposed to final achievement. They tended to compare pre-post measures and used their analysis of the initial models to guide their instructional strategy. My results are encouraging to teacher education programs because these findings suggested that a key role in any program should be engaging PTs in these tasks of analyzing student work as part of the reflection. By analyzing their students' artifacts, PTs can potentially begin to move away from the perspective of "get it or don't get it" towards a more interpretive stance. Additionally, analyzing student work could provide the PTs with more informative instructional moves that correspond to their students' learning pattern.

In the final investigation conducted, I examined how the three components of *developing an awareness of student thinking,* specifically attending, interpreting, and hypothetically responding, changed over the course of the teacher education program by analyzing the PTs' critiques of student models. I found that PTs tended to be interpretive in their analyses of student thinking which was surprising since others, such as Morris, (2006), observed PTs to be more descriptive. Additionally, I noticed that as the teacher education program progressed the PTs became more explicit and detailed in their hypothetical follow up lessons and the lessons were more connected to their analyses of the student artifacts. Again, this was surprising since Jacobs et al, (2010) found that PTs did not know how to help students ameliorate misunderstandings.

The second focus of this investigation was examining similarities and differences between PTs' critiques of student models and experienced inquiry teachers' critiques. I found that the experienced teachers did not view lessons as isolated events (as the PTs had) but were connected to a bigger picture, such as the big idea of the unit. Moreover, the experienced teachers were better able to break down student thinking into the sequence of concepts that the students need to learn in order to understand the topic.

Based on the results of all three investigations, it is evident that PTs do account for student ideas to varying degrees. Further, it seemed that PTs tended to become more cognizant and interpretive of student understanding as the teacher education progressed. Although there are some differences between how the PTs and experienced inquiry teachers assessed student learning, the results suggested that PTs do take into account student ideas when reflecting on lessons as well as analyzing static student artifacts. This is encouraging to teacher educators because previous research has suggested that PTs do not account for students and their ideas when designing lessons. It seemed that engaging in reflective practices, whether it is reflecting on lessons taught or analyzing static artifacts for understanding, is beneficial to the *developing an awareness of student thinking*.

5.2 Future Research

Based on the findings of this work, two areas of study warrant further investigation: (a) further investigation of frames or lenses of analyses using a larger sample size and (b) a longitudinal study that follows the PTs into the first two years of in-service teaching. Expanding the sample size of PTs would enable researchers to determine what other types of frames or lenses PTs use when reflecting on lessons. Currently, we have been able to characterize six frames with varying degrees of attention to student thinking; however, using a larger sample size would provide a more thorough analysis of what other frames, if any, PTs may employ.

In addition, following the PTs into the first two years of in-service teaching will be informative for several reasons. First, it would be interesting to examine how the frames the PTs employed changed or developed over the course of this two year time frame. Next, this investigation would be able to explore how PTs' interpretation of student ideas guided future instructional design. Finally, this study would be able to examine how PTs' PCK, specifically attention to students' ideas, developed from their teacher education program to their first years of teaching. Overall, a longitudinal study would provide a more complete picture as to how the precursors of noticing changed or developed into the practices of noticing.

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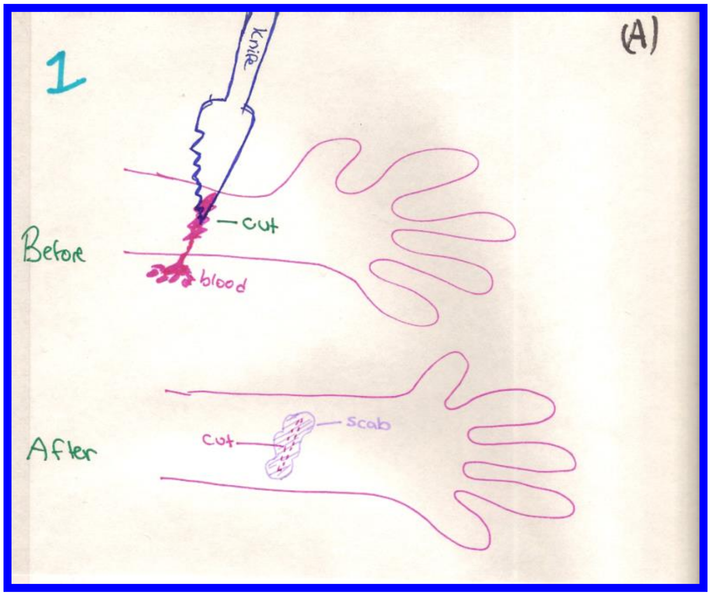
Appendix A

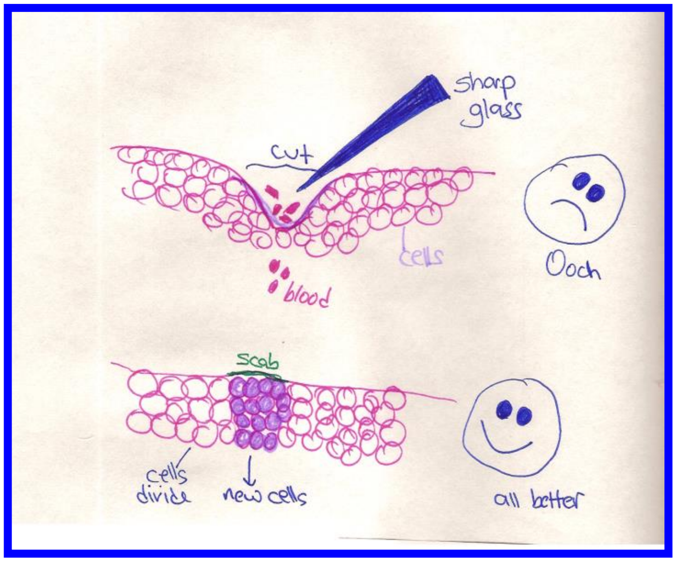
Cellular Division Model Set

Model #1:



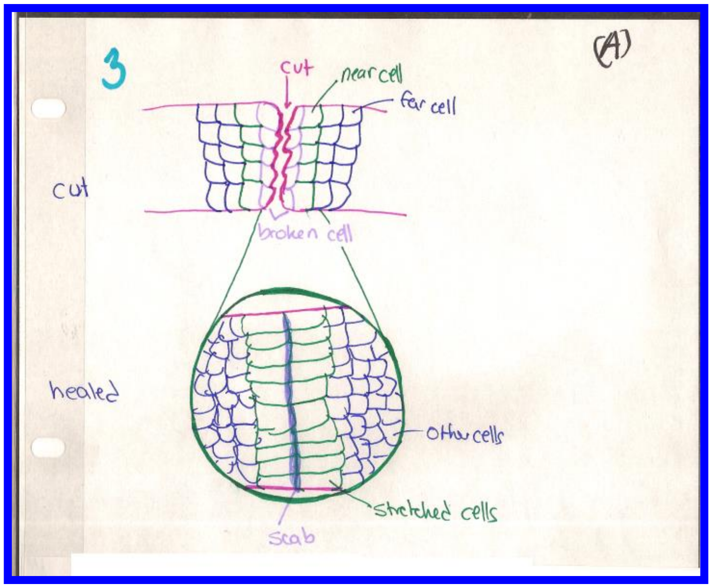
When you get a cut then after a week a scab forms on it. I know this because I saw pictures of scabs and when I look with a microscope you can see the scabs.

Model #2:



When you get a cut then the skin cells that are not cut multiply. The cells multiply to make new cells that heal the cut so your skin is better.

Model #3:

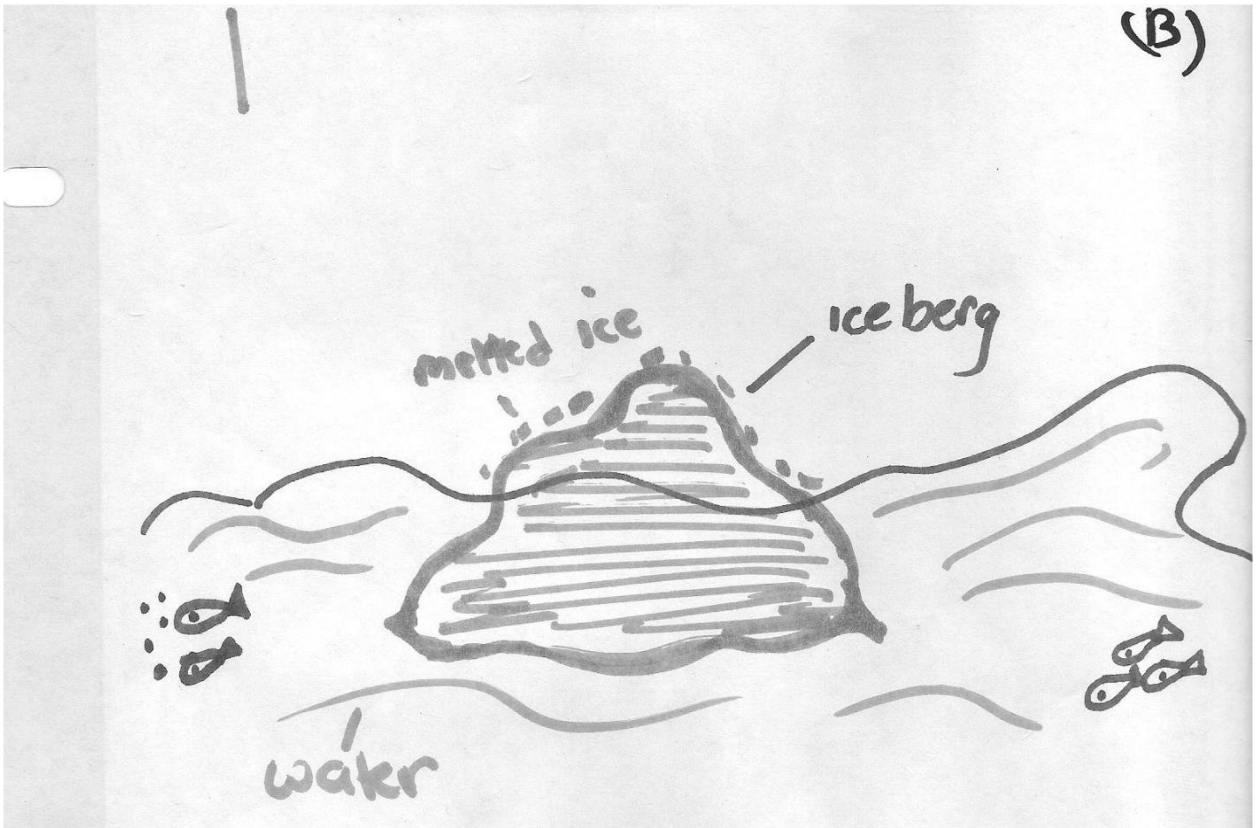


When you get cut the cells are broken and die. The cells near them grow bigger and fatter to fill the space. I know this is right because after a cut the healed skin is very smooth and stretched because the cells in it expanded.

Appendix B

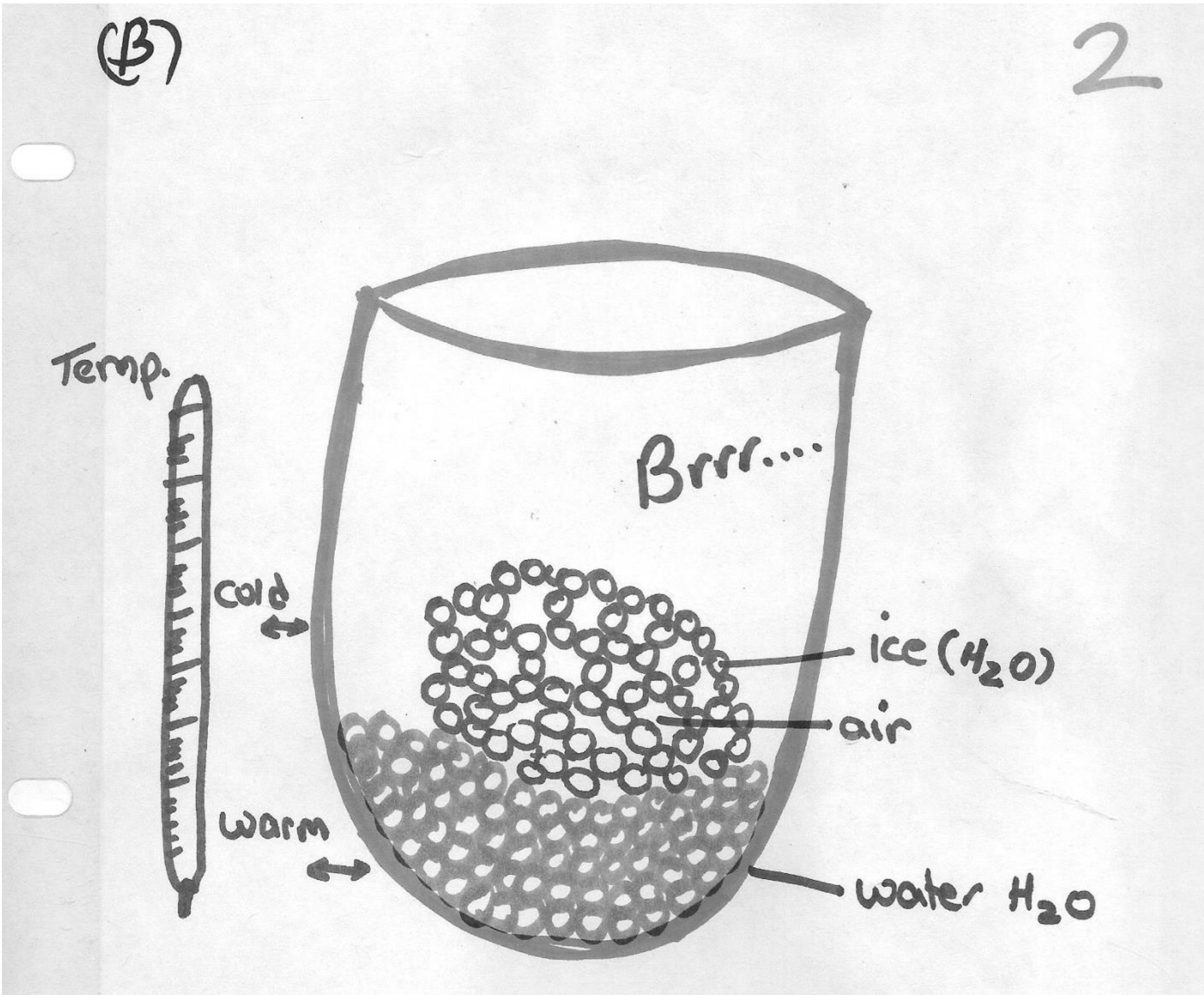
Density Model Set

Model #1:



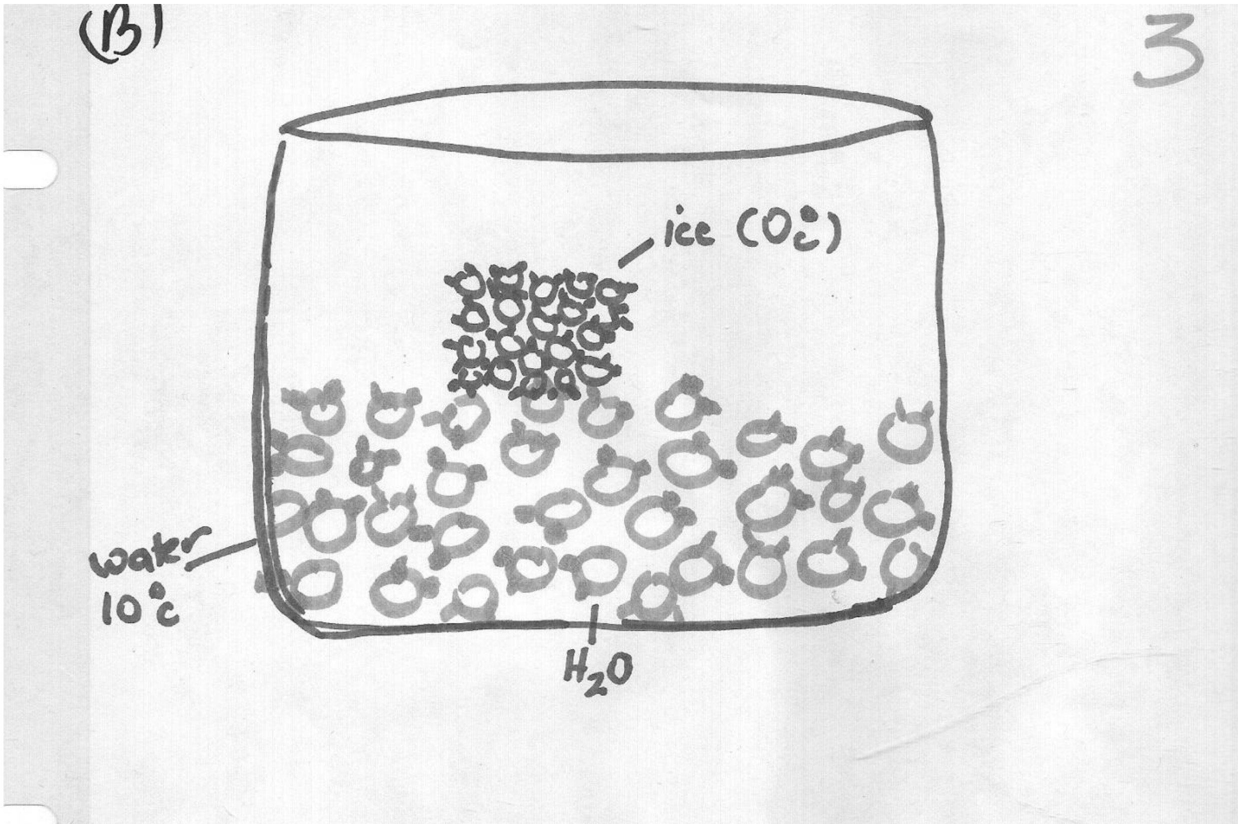
When it gets very cold water turns to ice. The ice floats on the water. I know because big icebergs are always more under the water than on top. You can only see the tip of the iceberg.

Model #2:



When water molecules are cold they don't move a lot and they stick together. The ice has more spaces with air in it so if floats on water.

Model #3:



Water molecules in ice become smaller and are less dense and they stick together to make ice. I know this because when it gets very cold outside stuff shrinks, like metal and because ice floats it must have small and shrunked molecules.