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Exploring the Relationship between Teacher Professional Noticing and Responsive Teaching in Experienced Secondary Science Teachers

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Exploring the Relationship between Teacher Professional Noticing and Responsive Teaching in Experienced Secondary Science Teachers

A dissertation submitted in partial satisfaction of the requirements for the degree Doctor of Philosophy

in

Mathematics and Science Education

by

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2021

The Dissertation of Lauren Nicole Emery is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

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2021

Dedication

For Devin – You are my rock. You have been by my side to celebrate all my successes and to support me through my failures. My life is better with you in it.

For my parents – You have supported me through every journey that has gotten me to where I am today. Know your actions have not gone unnoticed.

For my grandma – Your love and dedication to our family over the years has shaped me into the woman I am today.

For my grandpa – I wish you were here with us today. I hope I am making you proud.

Epigraph

I was taught that the way of progress was neither swift nor easy.

Marie Curie

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List of Abbreviations

NGSS	Next Generation Science Standards
NRC	National Research Council
PD	Professional Development program
LLfT	Learning to Learn from Teaching
PACT	Performance Assessment for California Teachers
CP	Content and Practice
TMCF	Teacher Moves and Classroom Features

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Stewart, L., Ross, D. L., and Elliot, K. (2019). Genetics for All: Supporting Targeted Populations in Biology. *The Science Teacher, 86*(8); p. 42-47.

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Abstract of the Dissertation

Exploring the Relationship between Teacher Professional Noticing and Responsive Teaching in Experienced Secondary Science Teachers

by

Lauren Nicole Emery

Doctor of Philosophy in Mathematics and Science Education

University of California San Diego, 2021
San Diego State University, 2021

Professor Meredith Houle Vaughn, Chair

The Next Generation Science Standards (NGSS) have invigorated a large push towards the expectation that students should engage in science as scientists do. This requires teachers to have the skills necessary to able to hear and engage with their students' science ideas. The current study draws from two constructs, teacher professional noticing and responsive teaching. Noticing includes; attending, interpreting, and responding to students' ideas (Jacobs et al., 2010). Similarly, responsive teaching includes; elicitation, interpretation, and following-up to students'

in-the-moment thinking (Levin et al., 2009). Richards and Robertson (2016) suggest noticing is a precursor to responsive teaching, however, no empirical study examines this relationship.

The current study takes place in the context of a larger study, the Noyce Project LEARN Master Teacher Fellowship, a five-year professional development program (PD) for 32 practicing mathematics and science teachers. This program had an explicit focus on students' mathematics and science ideas. Using two professional noticing tasks collected during the PD program, I identified three science teachers who increased in their capacity to engage in noticing skills over the five-year period. Classroom video was collected annually from each teacher, and I used discourse analysis, namely redirections (Lineback, 2014), to examine teachers' responsiveness to students' scientific thinking.

While I found minimal evidence for teacher responsiveness, I found a high presence of not responsive activity redirections. These occur when a teacher makes a comment or poses a question which shifts the activity, not in response to a student idea. I identified five not responsive activity redirections in my dataset; 1) whole class discussion, 2) developing/revising explanations/models, 3) surface level tasks, 4) small groups/partner discussions, and 5) conducting observations/investigations. When comparing the noticing task and classroom video, I noted a relationship in the types of not responsive activity redirections teachers engaged in and increased complexity teachers describe similar activities in the noticing task. While I did not observe evidence between growth in noticing skills and responsiveness, I have begun to illustrate the relationship between these constructs. Future research should expand the redirections coding framework to account for teacher redirections that occur during small group work, as this may indicate higher responsiveness in secondary classrooms.

Chapter 1: Introduction

Motivation

California, like many states in the U.S., recently adopted the Next Generation Science Standards (NGSS) or NGSS-like standards. NGSS was released for adoption in April 2013 after a two-year-long development process led by the National Research Council (NRC), National Science Teaching Association, American Association for the Advancement of Science, and Achieve ("Developing the Standards," n.d.). There are seven major conceptual shifts in NGSS (NGSS Lead States, 2013), three of these shifts are particularly relevant to my study, and are listed below:

1) Science education should reflect the ways that science is practiced by scientists and is experienced in the everyday world.
2) NGSS is built around student performance expectations.
3) The focus of NGSS is on a deeper understanding of content and its application.

With the expectation that students are to engage in science as scientists do and if students are expected to obtain a deeper understanding of science content, it is imperative teachers have the skills needed to see, hear, interpret, and respond to their students' ideas and practices. Moreover, with performance expectations clearly defined, it is crucial that teachers are able to help support their students to reach these defined expectations by the end of instruction. These conceptual shifts necessitate that science teaching shift from lecture-based teaching to inquiry-based science and phenomenon-based teaching. Inquiry science and phenomenon-based teaching center around the student instead of the teacher, prioritizing the prior knowledge and prior experiences that students bring into the science classroom. When students' thinking is prioritized in the classroom, it is important to understand how teachers understand and engage with their students' thinking.

Constructivism and the Next Generation Science Standards

The constructivist theory prioritizes individual experience. More specifically, in constructivism, learning is the process of an individual's active construction of their own knowledge about the world around them (Bodner, 1986; Piaget, 1947/2002). von Glasersfeld (1995) explains that learning occurs when an individual's current knowledge of the world is not sufficient for understanding a given situation and therefore a new construction of understanding must take place. Therefore, knowledge obtained is organized through physical or mental activity. When education researchers and teachers maintain a constructivist perspective, they recognize that students' existing knowledge and prior experiences shape the ways that students continually build their understandings about the world.

The NGSS are aligned to the constructivist view of learning. This is evident in the NGSS' major conceptual shift relating to the science and engineering practices. More specifically, NGSS shifts science education towards a reflection of the science practices that scientists employ in their work. The NGSS include eight science and engineering practices that students are expected to perform and master by the completion of twelfth grade.

> "In the future, science assessments will not assess students' understanding of core ideas separately from their abilities to use the practices of science and engineering. They will be assessed together, showing students not only "know" science concepts; but also, students can use their understanding to investigate the natural world through the practices of science inquiry, or solve meaningful problems through the practices of engineering design," (NGSS Lead States, 2013, Appendix F, p. 1).

The eight practices are: 1) asking questions and defining problems, 2) developing and using models, 3) planning and carrying out investigations, 4) analyzing and interpreting data, 5) using mathematics and computation thinking, 6) constructing explanations and designing solutions, 7) engaging in argument from evidence, and 8) obtaining, evaluating, and communicating information (NGSS Lead States, 2013). When considering constructivism together with the conceptual shift towards scientific practice, we see the two are very much aligned. Piagetian constructivism requires that learners engage in active construction of the knowledge around them (Bodner, 1986; Piaget, 1947/2002), and by engaging in the scientific practices outlined by NGSS, learners are able to engage in the active construction of their own knowledge, which is a requirement for learning.

The connections between constructivism and NGSS is also evidenced through the performance expectations included in NGSS. The performance expectations are the measurable outcomes that educators use to determine if their students have reached a sufficient understanding of science content and practice.

> "Performance expectations simply clarify the expectations of what students will know and be able to do be the end of the grade or grade band. Additional work will be needed to create coherent instructional programs that help students achieve these standards," (NGSS Lead States, 2013, Appendix A, p. 2)

When we consider that constructivism holds the view that knowledge must be consistent with reality and knowledge is consistently built and retested (Bodner, 1986), we see that in its very foundations, NGSS and constructivism are connected. When developing instruction for their students, teachers must consider their students' prior knowledge in order to make well-informed instructional decisions. As such, NGSS allows educators to create instructional plans based on their unique set of students, and the experiences and knowledge that each student brings to their classroom. When teachers acknowledge the variety of experiences and understandings that their students bring into the classroom, it is crucial that teachers are prepared to elicit and attend ideas and experiences.

Finally, I have identified that NGSS' shift to focus on a deeper understanding of content and its application is also closely related to constructivism and the present study. Because NGSS focuses on a smaller set of disciplinary core ideas (DCIs), students are revisiting these DCIs throughout their kindergarten to twelfth grade educational careers. This permits students to continually build on their existing knowledge to gain more scientifically accepted understandings about the world around them.

> "The core ideas also can provide an organizational structure for the acquisition of new knowledge. Understanding the core ideas and engaging in the scientific and engineering practices helps to prepare students for broader understanding, and deeper levels of scientific and engineering investigation, later on—in high school, college, and beyond," (NGSS Lead States, 2013, Appendix A, p. 5)

By creating standards that are organized in this way, we acknowledge the importance of students' continued experience with ideas and their ability to rebuild their knowledge as they engage in new experiences. This runs parallel with constructivism because the focus is, again, on the learner and their construction of their knowledge over time. NGSS and constructivism highlight the importance of teachers' abilities to elicit students' prior knowledge and current constructions of knowledge in order to support their deeper learning of the scientific content.

Illustrative Vignettes

In the next section, I present transcripts from whole-classroom discussions in two different science classrooms. The teachers' discourse is presented in bold. After each transcript, I briefly highlight some key characteristics in the teachers' discourse and the students' discourse. After presenting and discussing both individual transcripts, I draw comparisons between the two classrooms, and connect these characteristics to constructivism and study motivations.

A Non-Responsive Whole-Class Discussion

The following transcript is published in Eliasson, et al. (2017) and exemplifies discourse in what I would consider to be a non-responsive classroom. In this classroom, the teacher poses a question with an intended answer in mind. As their students begin to answer the initial question, the teacher poses subsequent guiding questions, leading their students to the teacher's intended answer.

Teacher: Now I would like to ask you one thing. What have you … what conclusions have you drawn about the labs? For all lab stations?

Student 1: I have not drawn any conclusions. I just wrote.

Teacher: But what do they all have in common?

Student 2: Most of them are about kinetic energy and potential energy.

Student 3: And about heat as well.

Teacher: But what happens to the energy?

Student 4: It is transformed.

Teacher: Transformed, Ok. Energy is converted.

One of the most apparent characteristics in this transcript is that the questions that the teacher is asking their students have one intended answer: energy is transformed. Student 2 proposes the most accepted answer by the teacher and as such the teacher pursues this response, seemingly ignoring that student 3 mentions heat. By the teacher continuing this line of questioning, we reach an answer that the teacher accepts and stops probing their students, the idea that energy is transformed or converted. Student 3's idea of heat energy is not pursued by the teacher in this exchange. During this excerpt, the teacher leaves no room for students to ask questions about the investigation or energy, the focus of the exchange is getting students to the final idea, that energy is converted.

A Responsive Whole-Class Discussion

The second transcript is published in Coffey and Windschitl (2016) and exemplifies an inquiry-based classroom with student-centered discourse. In a student- or learner-centered classroom, instruction utilizes tools that engage the students and guide (not disseminate) understanding.

Student 1 [hand raised]: It's something about making heat energy. It relates.

Teacher: So changing to heat energy?

Student 1: But it relates, um, my dad just got a um when we were in Portland my Dad got this special new [inaudible] kind of flint and steel. And technically the old one is since it's using iron and flint it's um the electrons are hitting...

Teacher: Flint's a kind of rock, right? I just want to make sure we're all visualizing this.

Student 1: It's a big sharp, it's a big black sharp rock.

Teacher: What do you use it for?

Student 1: You use it for, there's a special steel thing like this you put it in your hand, the old Individual one and you go like that and you do it as hard as you can and it will make a big spark.

Student 2 [shouts out]: Yeah, my dad has one of those.

Teacher: So you're turning the mechanical, the friction, energy where you rub into like heat energy with a spark?

Student 1: And then there's a special one...

Student 3 [interrupting]: You can do the same thing with two rocks

Teacher: Hold on, let him finish. Gary, can you finish your thought then Brady can add on.

Student 1: Um and then they also have these special ones where there's a scraper, a wood handle, a piece of I don't know what it's called. It's this light really, really flammable metal .. um and it has then it has a big bump of flint on it.

Despite the discourse in this transcript primarily being between the teacher and one student, this excerpt is from a larger whole-class discussion. The teacher in this classroom asks a variety of questions, requests the student clarify his ideas, repeat the student's ideas, and allows for another student to elaborate. The teacher is allowing their students to drive the discussion and acts as a moderator.

When comparing the two transcripts, I want to consider teacher talk first. In the first transcript, the teacher asks questions that guide students to a particular science concept, that energy can be transformed. In contrast, the teacher in the second transcript asks questions to repeat or clarify student ideas. In the second transcript, the teacher is allowing student 1 to guide the conversation. The teacher is asking clarifying questions along the way, "Flint's a kind of rock, right?" and "So you're turning the mechanical, the friction, energy where you rub into like heat energy with a spark?" The structure of the whole-class discussion in the first transcript is teacher-driven and in the second transcript, the discussion is student-driven. Transcript one represents a teacher-centered, ask and answer format, where the teacher is deciding what direction the conversation will go. In the second transcript, the teacher is allowing their students develop and investigate their own ideas in relation to science content. The second transcript illustrates how a learner-centered classroom allows for the students to determine the direction of the discussion, with the teacher helping to clarify ideas or mediate conversation.

Next, I want to consider the student talk. The student ideas being presented in the first transcript are limited. Students are not asked to explain their thinking or elaborate on the terminology that they are using. The teacher, instead, continues their line of questioning to reach the overall content goal of the lesson, energy can be transformed. This answer is completely removed from its context of the experiment that the students conducted and could simply be memorized from a textbook or lecture. In the second transcript, the students author their own ideas and the science is in the context of a familiar example. Here, one student talks about a rock that their father has and how hitting the rock (mechanical energy) results in a spark (heat energy). The teacher in the second transcript allows their students to explore science content based on their own experiences, making the discussion more relatable, meaningful, and student-driven.

When we consider the NGSS, we picture a classroom that looks more similar to the second transcript. Here, the teacher is allowing their students to develop their own ideas, explanations, and understandings. This classroom is also aligned to constructivist theory, where learning is a process driven by the student, not the teacher. The second transcript shows how students in this classroom think about the applications of content. Their thinking is contextualized in relevant, real world experiences. Although there is always room for improvement, science education researchers would like to see teacher-driven classrooms, like those in transcript one, develop into student-driven classrooms, like those in transcript two. In order to support these developments, it is important to understand: 1) how teachers attend to student thinking, 2) how teachers respond to student thinking, and 3) how to support teachers in eliciting and responding to students' ideas in their classrooms. In the next section, I will discuss two constructs that enable researchers to understand these particular aspects on instructional practice.

Teacher Professional Noticing

Teacher professional noticing is one theoretical construct that is used to understand how teachers understand and interact with students' ideas in the classroom. Teacher noticing consists of three component skills, recognized in both mathematics and science education literature: 1) attending to students' ideas, 2) interpretation of students' ideas, and 3) responding to students' ideas (Barnhart and van Es, 2015; Jacobs et al., 2010; van Es and Sherin, 2008). Studies on teacher professional noticing in both mathematics and science education examine how teachers interact with student thinking outside of the classroom. Examples of this include studies around professional development (Jacobs et al., 2010), video-based courses (Barnhart and van Es, 2015; Sun and van Es, 2015; van Es et al., 2017; van Es and Sherin, 2008), teacher preparatory courses (Benedict-Chambers, 2016; Talanquer et al., 2013; Talanquer et al., 2015), interviews (Kisa and Stein, 2015; Osmanolgu et al., 2015; Russ and Luna, 2013), and lesson study (Amador et al., 2016). Many of these studies examine teacher professional noticing in teacher candidates and/or elementary teachers (Amador et al., 2016; Barnhart and van Es, 2015; Benedict-Chambers, 2016; Osmanoglu et al., 2015; San and van Es, 2015; Talanquer et al., 2013; Talanquer et al., 2015; van Es and Sherin, 2008; van Es et al., 2017). Whereas few studies include experienced, secondary teachers (Dreher and Kuntze, 2015; Furtak et al., 2016; Kisa and Stein, 2015; Jacobs et al., 2010; Russ and Luna, 2013).

Responsive Teaching

Related to teacher professional noticing is the construct of responsive teaching, which can also be used to understand how teachers effectively respond to their students' ideas and understandings. Responsive teaching can be defined as the: 1) attention to students' ideas, 2) drawing disciplinary connections between student ideas, and 3) taking up and pursuing students' thinking (Robertson et al., 2016). Goodhew and Robertson (2017) simplify this definition to foregrounding students' ideas, seeking out disciplinary connections between ideas, and formulate construction on the basis of student ideas.

Many of the studies in responsive teaching examine the responsiveness to students in elementary classrooms (Coffey and Windschitl, 2016; Goodhew and Robertson, 2017; Hammer et al., 2012; Johnson et al., 2017; Lineback, 2014; Maskiewicz and Winter, 2012). Few responsive teaching studies examine responsiveness in secondary level classrooms (Dyer and Sherin, 2015; Levin et al., 2012; Pierson, 2009). Unlike teacher professional noticing, the context for studying teachers' responsiveness is more consistent. Most of the studies identified and reviewed here examine teachers' responsiveness through examination of classroom observation and/or video (Coffey and Windschitl, 2016; Dyer and Sherin, 2015; Goodhew and Robertson, 2017; Hammer et al., 2012; Levin et al., 2009; Levin et al., 2012; Lineback, 2014; Maskiewicz and Winter, 2012; Pierson, 2009). Only two studies used interview methods to understand teachers' responsiveness to student thinking (Dyer and Sherin, 2015; Johnson et al., 2017).

Proposed Conceptual Framework

While the literature on teacher professional noticing and responsive teaching cross-reference each other frequently, I found no literature that explicitly connects the two frameworks. One goal of this study, described below, is to provide empirical evidence for whether these frameworks support each other. Therefore, the conceptual framework that underlies the current study considers these two areas of literature. My proposed conceptual framework follows:

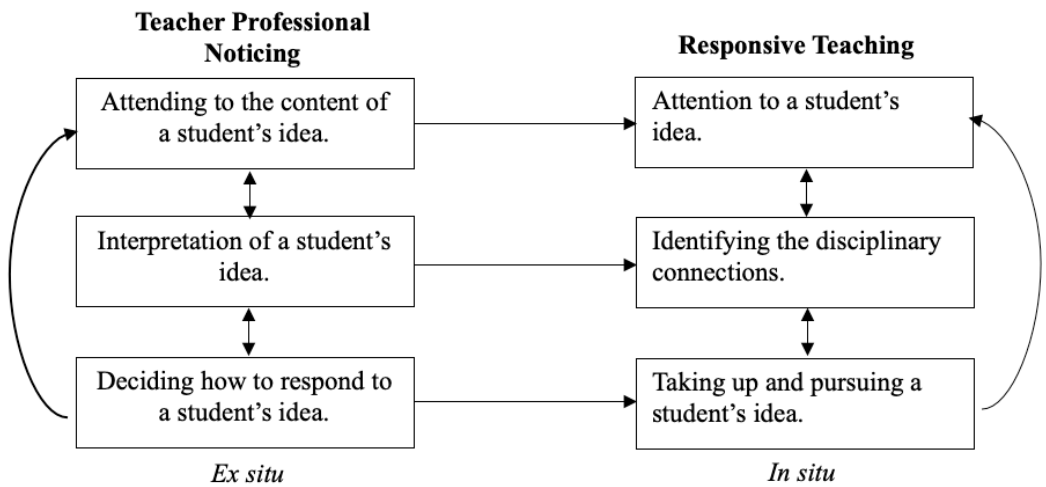

Figure 1.1: Proposed framework for the relationship between teacher professional noticing and responsive teaching.

Richards and Robertson (2016) explain that teacher professional noticing skills are important precursors to responsive teaching. As such, I have included horizontal arrows in the diagram above, indicating movement from teacher professional noticing to responsive teaching. I propose that as teachers increase in their abilities to attend, interpret, and respond to student thinking (teacher professional noticing), they will begin to increase in their attention to students' ideas, their ability to identify disciplinary connections, and take up and pursue students' ideas (responsive teaching).

For both teacher professional noticing and responsive teaching, I have arrows that connect each "component skills," in reflexive directions (both up and down). The purpose of these arrows is to indicate the connectedness between the skills in each individual conceptual framework (for teacher professional noticing and responsive teaching). It is important to recognize these practices inform each other, and experienced teachers will not simply attend, interpret, and respond to student thinking in a linear fashion. Rather this internal decision-making requires feedback. This is also why responding and taking up students' ideas have arrows pointing back to attention for both frameworks. Jacobs and colleagues (2010) conclude that increased experience with students' thinking (via teaching and PD) resulted in increased engagement in attending, interpreting, and responding to student thinking. Similarly, Goodhew and Robertson (2017), conclude that attention to student ideas is a critical first step in responsiveness, followed identifying connections. The authors explain that these skills are necessary for teachers to be able to take up and pursue student thinking (Goodhew and Robertson, 2017).

Finally, I have included the terms "ex situ" and "in situ" at the bottom of the diagram. I have included these terms to indicate the space in which these frameworks exist. For example, teacher professional noticing studies occur mostly outside of a teacher's classroom, such as in PD, lesson study, interviews, and teacher-preparatory courses. Because of this, I indicate the teacher professional noticing occurs ex situ, meaning outside of the classroom. I have indicated responsive teaching occurs in situ, inside the classroom. This is because much of the literature on responsive teaching takes place in the classroom, using classroom video and examining discourse using transcripts.

When we consider the parallels between teacher professional noticing and responsive teaching, we can see that both frameworks can and should be used to inform the other. Both conceptual frameworks support the endeavor of learning how teachers attend to, understand, and make instructional decisions based on the information that they are actively receiving from their students. I believe that by examining teachers who have worked extensively in learning how to notice, we can then use the responsive teaching framework to understand how teachers' classroom practices have shifted.

Study Goals and Research Questions

One primary goal for the proposed study is to provide evidence for whether the development in secondary teachers' professional noticing skills is related to development in teachers' responsiveness over the course of five years of PD. This is postulated by Richards and Robertson (2016), though there is currently no empirical evidence to support this idea. Another goal of the proposed study is to discourse analysis, the redirection, to study teachers' responsiveness over time and to compare responsiveness across multiple teachers. Below are the research questions that I am proposing to drive my study:

1) In what ways does teachers' responsiveness to student thinking shift during an extended professional development program with a focus on students' scientific thinking?
2) In what ways do teachers grow in relation to their professional noticing skills and their responsiveness to student thinking, during the course of a five-year professional development program focused on student thinking?
3) During instruction, what instructional moments do teachers identify as critical moments, and how do these moments relate to teachers' responsiveness to student thinking?

Chapter 2: Literature Review

Introduction

Richards and Robertson (2016) proposed that teacher professional noticing is a critical precursor to responsive teaching. Through the present study, I seek to provide the first empirical evidence connecting these two constructs. The purpose of this literature review is to review the foundational and current literature on the topics of teacher professional noticing and responsive teaching in both science and mathematics. I will highlight key methodologies for studying teacher professional noticing and responsive teaching. I will also highlight key findings in this literature. The primary goal of this literature review is to demonstrate the parallels between the studies examining teacher professional noticing and responsive teaching.

Defining the Frameworks

Jacobs, Lamb, and Philipp (2010) define teacher professional noticing "… as a set of three interrelated skills: attending to children's strategies, interpreting children's understandings, and deciding how to respond on the basis of children's understandings," (p. 172). Barnhart and van Es (2015) draw upon Jacobs, et al. (2010) by defining teacher professional noticing as "… attending to what is noteworthy in classroom data, analyzing, and interpreting that data with respect to defined goals, and deciding how to respond," (p. 85). Similar to teacher professional noticing, responsive teaching is composed of three themes. Levin, et al. (2009) define responsive teaching as the elicitation, interpretation, and following-up to students' thinking in-the-moment of instruction. Robertson and colleagues (2016) similarly define responsive teaching as being composed of: foregrounding student ideas, recognizing disciplinary connections, and taking up and pursuing student thinking.

The definitions for teacher professional noticing described above represent the widely used and accepted definitions for this construct in the literature. The definition for responsive teaching is a bit messier. Johnson and colleagues (2017) define responsive teaching as eliciting student ideas, noticing and interpreting important aspects of these student ideas, and responding to the student to support learning. Colley and Windschitl (2016) describe responsive teaching as a cyclical process in which a teacher asks an open-ended question, a student responds to this question, then the teacher will select a particular aspect of this idea to further consider, asking other students to engage with this idea. Kisa and Stein (2015) describe responsive teaching as engaging in attention to student sense-making and actively assisting students in the development of their thinking without thinking for them. While these other definitions for responsive teaching focus on components where the teacher is engaged in supporting student learning, one acknowledges the cyclical nature of this process (Colley and Windschitl, 2016), while another definition recognizes that teachers support student thinking but do not do the thinking for their students (Kisa and Stein, 2015). These two examples do not embody the three-part process of responsive teaching described in the prior paragraph.

Authors examining responsive teaching and teacher professional noticing often cross-reference the literature when it comes to defining what effective classroom teaching looks like. Literature in responsive teaching often refers to teacher professional noticing and vice versa. However, until Richards and Robertson's (2016) claim that teacher professional noticing is an important precursor to responsive teaching, the connection between these two frameworks had not been described.

Upon consideration of the definitions for teacher professional noticing and responsive teaching, it appears that the skills that teachers engage in for teacher professional noticing are internal. Paying attention to student thinking, making interpretations about these ideas, and deciding how to respond are all processes that researchers need to be made visible in order to study. In contrast to this, the definitions for responsive teaching imply external mechanisms. As an observer, we can hear the questions teachers ask to elicit student thinking and we can hear how teachers respond to this idea (or do not respond). These distinctions likely shape how researchers select their methodologies to examine teacher professional noticing or responsive teaching. In the sections below, I will describe some of the commonly used methods for each framework.

Methodologies

Methods Used in Teacher Professional Noticing Studies

While literature around teacher professional noticing is extensive in mathematics education, literature of teacher professional noticing in science is still fairly limited. This section will focus on a core set of teacher professional noticing studies conducted in the disciplines of mathematics and science education, organized around the primary methodologies used in each study. When taking a deep-dive into the literature, multiple different methodologies for studying teacher professional noticing emerged from the literature: 1) studies situated in the context of a video-based course, 2) the use of a professional noticing task, 3) analysis of transcripts of whole-group discussions among teachers, 4) interview-based techniques, 5) examination of classroom discourse, and 6) questionnaires.

Video-based courses are used in at least three studies to support teachers in learning to attune themselves to students' ideas (Barnhart and van Es, 2015; Sun and van Es, 2015; van Es et al., 2017). These studies were set in the context of teacher preparation methods courses, and took place in the context of a larger project called Learning to Learn from Teaching (LLfT). LLfT is a video-based course used to support teachers in learning to notice student thinking and interpret these ideas (Barnhart and van Es, 2015; Sun and van Es, 2015). Of these studies, two are from science education (Barnhart and van Es, 2015; Sun and van Es, 2015) and one is from mathematics education (van Es et al., 2017). To exemplify the video-based course studies, I will describe the specific methodology used by Barnhart and van Es (2015). This study compared a group of 16 preservice science teachers enrolled in a LLfT science methods course with a group of eight preservice science teachers enrolled in a standard science methods course. Preservice teachers' responses to the Performance Assessment for California Teachers (PACT) were used to understand how preservice teachers engage in teacher professional noticing. For the PACT, teachers submit a three-to-five-day lesson plan, including an assessment tool, student work samples, classroom video, and a reflection on the lesson. The authors analyzed the preservice teachers' written responses on the PACT using both qualitative and quantitative methods to understand how the participants viewed and analyzed teaching. Barnhart and van Es (2015) examined what the preservice teachers attend to when observing their teaching, how they analyzed (or interpreted) the sense-making events in the classroom, and how the preservice teachers used student ideas to inform future teaching (responding). The other studies based in the context of the LLfT course use similar methods but differ in the data that was analyzed. Sun and van Es (2015) examined classroom teaching videos that preservice teachers submitted for PACT, and van Es and colleagues (2017) examined preservice teachers' classroom teaching before and after the LLfT course or a traditional methods course. The affordance of using the LLfT course to study teacher professional noticing is that the authors are able to have a control and experimental group to understand how teacher professional noticing skills are developed over the duration of the LLfT course. A constraint of this methodology, however, is that researchers are not examining what is happening inside of a classroom.

Another methodology used to understand teacher professional noticing is teacher professional noticing tasks. When I say "teacher professional noticing task," I mean a task that is administered outside of the classroom. Professional noticing tasks can be based on a classroom video (a whole video or segment), student work samples, or a combination of the two. Based on the instructional events and student ideas present in the video and/or work samples, the participants respond to a set of questions intended to elicit the teachers to attend, interpret, and respond to the classroom events, teachers' instructional moves, and/or students' ideas. Three science studies (Osmanolgu et al., 2015; Talanquer et al., 2013; Talanquer et al., 2015) and one mathematics study (Jacobs et al., 2010) used a professional noticing task to understand the complex sensemaking teachers engage in in the classroom. In the studies by Talanquer, et al. (2013), Osmanoglu, et al. (2015), and Jacobs, et al. (2010), the participants viewed a classroom video clip and were given corresponding student work samples. In Talanquer and colleagues (2015), teachers examined student work samples. In all four studies, participants were asked to reflect on the student ideas present in the classroom video and/or work samples. For example, Jacobs and colleagues (2010), one of the foundational professional noticing studies, examined teacher professional noticing in elementary teachers. These participants consisted of 36 prospective teachers and 95 practicing teachers who varied in the length of time they had participated in an extended professional development (PD) program (31 initial, 31 participating in two years, and 33 participating in at least five years of PD). This study used two artifacts to measure noticing skills called "The Lunch Count" and "M&M's". The Lunch Count artifact was a 9-minute video clip of a longer instructional segment and the M&M's artifact consists of written student work from three different students. The participants were given three prompts:

1) "Please describe in detail what you think each child did in response to this problem." (Attend)
2) "Please explain what you learned about these children's understandings." (Interpret)
3) Pretend that you are the teacher of these children. What problem or problems might you pose next?" (Respond) (Jacobs et al., 2010, p. 179)

The researchers then coded the prompts as: showing evidence to children's strategies or lack of evidence (attend); robust, limited, or lack evidence of interpretation of children's understandings; and robust, limited, or lack evidence of deciding how to respond on the basis of children's understandings. A professional noticing task is a way to collect data on teachers' attention to student thinking outside of the context of the classroom. The theory behind professional noticing tasks is that they best mimic the in-the-moment decision making that occurs in the classroom (Jacobs et al., 2010). However, these tasks can only be used to make inferences about how a teacher might reason when engaging in instruction.

A third approach education researchers use when studying teacher professional noticing are discussion-based methods. In science, Benedict-Chambers (2016) examined whole-group discussion of preservice teachers following instruction rehearsal. In mathematics, Amador and colleagues (2016) examined whole-group transcripts of discussion that occurred during lesson study conducted by preservice teachers. Also, in mathematics, van Es and Sherin (2008) examined the transcripts of group discussions between in-service elementary school teachers who share their classroom videos and engage in discourse around those videos. I will briefly describe the study by Benedict-Chambers (2016) here. The study participants were 16 preservice teachers who were enrolled in a master's level teacher credential program and a science methods course. During the course, the preservice teachers taught 15-20-minute instructional segments to a group of four peers and one teacher educator. Following the instruction rehearsal, the observing group spent 10-15 minutes discussing the preservice teacher's instruction. Videos and transcripts of these discussions were analyzed for the purpose of this study. Benedict-Chambers (2016) sought to understand what science teaching topics were discussed and the nature of post-rehearsal discussions. The transcripts were coded using the following discussion moves; identifying challenges, interpreting challenges, sharing insights to respond to challenges, describing instruction, and affirming instruction. The authors engaged in both a qualitative and quantitative analyses of the data. The discussion-based method used by Benedict-Chambers (2016) closely mimics what may be occurring inside of a classroom. Through instruction rehearsal, teachers are able to engage in discourse and ask questions about their own instruction, not the instruction of another teacher, such as in a professional noticing task.

Interviews have also been used to study teacher professional noticing. Kisa and Stein (2015) interviewed in-service high school biology teachers. During these interviews, the teachers analyzed videos of students engaged in cognitively challenging science tasks. During the interviews, participants were asked to discuss what they noticed during the videos. Russ and Luna (2013) interviewed a single high school biology teacher around the teacher's self-taught lessons. Russ and Luna (2013) observed and recorded four whole-class sessions. The teacher also used a small camera, placed on the teacher's body to capture critical moments. The camera was designed to constantly stream video, and when the record button was pressed, the previous 30-seconds of footage was stored. The teacher in this study was asked to record "interesting" moments during instruction. During the interview, the teacher and researcher watched each 30-

second video clip until the teacher recognized the moment. Once the teacher indicated recognition, the video clip was paused and the teacher explained why they thought that moment was interesting and what student ideas were present. The researchers analyzed the teacher's "interesting" clips and their reflections from the interviews. These data were coded and the researchers sought to understand what activities students engaged in, what students learned, and what the role of the teacher was. Both qualitative and quantitative analyses were conducted. It seems that the interview techniques by Russ and Luna (2013) most closely reflect what sense-making teachers engage in inside the classroom. By having the teacher record important moments and then reflect upon these moments, researchers are able to get an idea of the reasoning teachers were engaged in during instruction. Despite this affordance, it is also possible that a teacher may not be able to recall why they indicated every moment important or their reasoning may be different than it was during the actual moment of instruction.

Finally, less frequently used techniques to examine teacher professional noticing are classroom discourse analysis and questionnaires. Furtak and colleagues (2016) examined one mathematics and science lesson taught in a middle school classroom. They analyzed the classroom discourse that occurred throughout the lesson and also analyzed the results of students' performance on a post-lesson assessment. Dreher and Kuntze (2015) examined results from a questionnaire they administered to preservice and in-service mathematics teachers. This questionnaire sought to understand how teachers perceive how their content knowledge, personal views, and levels of teaching experience impact their abilities to notice student thinking. As we will see in the next section, the methods used by Furtak, Thompson, and van Es (2016) mimic common methods used by responsive teaching researchers. This discourse analysis affords the researcher the ability to understand what was happening during the moments of instruction, but requires inference on how the teacher thought about instruction. The study by Dreher and Kuntze (2015) appears to be the most out-of-context study. By using a questionnaire, researchers are not able to probe more deeply and the teachers' responses are much more limited.

While not exhaustive, the review above represents the current methodologies present in the literature used to examine how teachers attend to, interpret, and respond to students' scientific or mathematical thinking. They also represent the breadth of participants in current literature, demonstrating that most teacher professional noticing literature examines preservice teachers and elementary teachers. Out of the 14 articles on teacher professional noticing in science reviewed here, six examine teacher professional noticing in in-service teachers and eight studies examine teacher professional noticing in preservice teachers who are in a teacher credential program. Additionally, only five out of the 14 articles reviewed here examine teacher professional noticing skills in secondary educators, the remaining studies either focused on elementary level teachers or did not specify the grade level.

Methodologies Used in Responsive Teaching Studies

Many studies that examine responsive teaching do so in the classroom. Analysis of classroom discourse is the primary methodology is used by researchers investigating responsive teaching (Coffey and Windschitl, 2016; Hammer et al., 2012; Maskiewicz and Winter, 2012; Pierson, 2008). For example, Hammer and colleagues (2012) present a case study on a multi-day lesson implemented in a third-grade science classroom. The classroom discourse that occurred in the classroom was examined for the purpose of this study, and more specifically the discourse exchanges between the teacher and her students. The analysis in this study included the science ideas that the students shared, how the teacher interacted and supported these ideas, and how the ideas developed over the course of the multi-day lesson. Levin, et al. (2012) also present a case study, but in a high school science class. The authors analyzed a classroom transcript from a class discussion surrounding the topic “is air matter?” Levin and colleagues (2012) examined the teacher-student and student-student discourse in order to understand how the teacher supported their students in pursuing science. Goodhew and Robertson (2017) conducted in a case study surrounding a single-day discussion of energy in an elementary classroom. Their analysis consisted of three episodes in which they used talk-turns to understand teacher responsiveness. Within each episode, the researchers characterized the responsive move, content knowledge, and how the teacher’s talk move relied upon the teacher’s content knowledge. Maskiewicz and Winter (2012) conducted a case study with one experienced fifth grade teacher. They examined this teacher’s science class for two consecutive years. The authors examined classroom data including video of the lessons, field notes, classroom debriefs with the teacher, and interviews. The authors examined the roles that the teacher fulfilled and how these roles impacted the students’ roles in the classroom. Coffey and Windschitl (2016) conducted a larger case study to examine students’ ideas, experiences, and responses, and teacher discourse in two fourth grade and two fifth grade science classrooms. The authors used talk-turn analysis to analyze both teacher and peer responsiveness during whole-class discussions. Pierson (2008) examined how an experienced secondary mathematics teacher implemented a particular unit on rate of change and proportionality. The data that Pierson analyzed included video recordings of the units from each class, field notes, and results from pre- and post- student assessments. Videos were transcribed and broken down into episodes for analysis.

Another study utilizing classroom video and discourse is Lineback (2014). Lineback (2014) developed and exemplified a new method, the redirection, as a way to study how teachers take up and pursue their students’ thinking in the classroom. “A redirection can be defined as a teacher's bid to shift, refocus, or redirect the attention of the class from one scientific phenomenon/question/activity to another," (Lineback, 2014, pg. 12). The author explains that the redirection can be used to identify and characterize how a teacher responds to their students (Lineback, 2014). The author continues by explaining that redirections are sensitive enough to identify differences in a teacher's responsiveness moment-to-moment, but can also be used to observe differences in a teacher's responsiveness over time. By examining the type of redirections, their frequency, and their timing, researchers are better able to analyze teachers' responsiveness (Lineback, 2014). Lineback (2014) describes the many uses that redirections can afford researchers, including: 1) analyzing instructional practice, 2) monitoring a single teacher over time, and 3) comparing multiple teachers in relation to responsiveness.

Less common is the use of interview techniques to study teacher responsiveness (Dyer and Sherin, 2015; Johnson et al., 2017). Johnson and colleagues (2017) conducted semi-structured interviews with six elementary teachers. The teachers were participating in a larger study that included a week-long PD program and monthly meetings with the research team. In the interviews analyzed for this study, the elementary teachers were given the task of watching a video clip that highlighted student-student interaction. The teachers were asked what they noticed, specifically in regard to student thinking and behavior. Dyer and Sherin (2015) examined two high school mathematics teachers. In this study, the researchers had the teachers record important moments in real-time, during classroom instruction. Immediately following instruction, the authors conducted interviews to discuss why the teachers saved these particular moments.

One responsive teaching study used the largest variety of methods to understand where teachers focus their attention. Levin, et al. (2009) used multiple methodologies to study preservice teachers' responsiveness. These authors used classroom video recordings, field notes, teachers' course papers from a pedagogy course, interviews, and seminar discussions. In addition to the use of classroom recordings and/or interviews like the other reviewed studies utilized, Levin and colleagues (2009) also collected and analyzed discourse from the preservice teachers' preparation courses.

This review of research methodologies seeks to illustrate the most commonly used research techniques in the literature on responsive teaching. Out of the ten studies described above, seven examine in-service elementary teachers, two examine in-service secondary teachers, and one examines pre-service teachers. Similar to the studies examining teacher professional noticing, a large majority of studies examining responsive teaching are based in the context of elementary education. Unlike the studies in teacher professional noticing, responsive teaching studies mostly include participants that are practicing teachers.

Summary of Research Methods

Many of the methodologies used in teacher professional noticing are outside of the context of the classroom. These methods include; studies set in the context of video-based courses that examine instructional artifacts (e.g. lesson plans, student work samples, and assessments), professional noticing tasks, discourse between teachers, and questionnaires. In teacher professional noticing, only the studies using interview methods used the participants' own classroom video to reflect on. In contrast, the literature examining responsive teaching is often organized around classroom data. One of the core methodologies in responsive teaching is analyzing the discourse that happens during classroom videos. As with the literature on teacher professional noticing, interview techniques used in responsive teaching also centered around classroom video. It seems that researchers who examine teacher professional noticing do so mainly outside the classroom (*ex situ*) whereas researcher who examine responsive teaching do so mostly set inside the classroom (*in situ*).

Results Presented in the Literature

Results in Teacher Professional Noticing Studies

When considering the cumulative literature on teacher professional noticing, there are several key take-aways:

1) Supports such as PD, LLfT video-based courses, and group discourse around instruction support preservice and in-service teachers in their ability to notice student thinking.
2) Teachers focus primarily on describing student ideas and/or evaluating student ideas.
3) Teachers attend to classroom pedagogy, science practices, and teacher content knowledge.
4) Teacher professional noticing is challenging endeavor, it is not learned similarly across different individuals, and each skill is developed differently.

One key result in the literature on teacher professional noticing is that structured experiences support teachers in developing their professional noticing skills (Barnhart and van Es, 2015; Benedict-Chambers, 2016; Jacobs et al., 2010; Kisa and Stein, 2015; Sun and van Es, 2015; van Es and Sherin, 2008). Teacher professional noticing requires that teachers are able to attend to, interpret, and respond to students' ideas. Preservice teachers' ability to engage in these skills are supported through structured experiences (Barnhart and van Es, 2015; Benedict-Chambers, 2016; Sun and van Es, 2015). LLfT video-based courses supported teachers in developing their abilities to attend to, interpret, and respond to student thinking (Barnhart and van Es, 2015; Sun and van Es, 2015). Similarly, post-teaching rehearsal and discussion was found to support preservice teachers in all three component skills of teacher professional noticing

(Benedict-Chamber, 2016). Attention to student ideas is also supported through extended PD focused on student thinking in preservice and practicing teachers (Jacobs et al., 2010). Jacobs and colleagues (2010) demonstrated that teachers continued to improve in their ability to attend to student thinking through engagement of up to two years of PD. Additionally, the ability to respond to student ideas is not directly attributed to teacher experience alone (Jacobs et al., 2010). Video clubs also support in-service elementary mathematics teachers in paying more attention to students' mathematical ideas, while teachers who did not participate in the video clubs remained focused on classroom climate (van Es and Sherin, 2008). Similarly, in-service secondary science teachers decreased in the amount of evaluative comments they made over the course of participating in PD (Kisa and Stein, 2015).

Another common result in the literature on teacher professional noticing is that teachers most often describe and/or evaluate students' ideas, in contrast to engaging in attending, interpreting, and deciding how to respond to these ideas (Amador et al., 2016; Kisa and Stein, 2015; Sun and van Es, 2015; Talanquer et al., 2015). Evaluating students' ideas as correct or incorrect is commonly reported (Kisa and Stein, 2015; Sun and van Es, 2015; Talanquer et al., 2015). In addition to teachers evaluating their students' ideas, teachers also describe students' ideas (Amador et al., 2016; Talanquer et al., 2015). In addition to teachers describing and evaluating students' ideas, preservice secondary science teachers also commented on students' conceptual understanding, although less frequently (Sun and van Es, 2015). Teachers' content knowledge is identified as an important factor in how teachers evaluate their students' understanding (Talanquer et al., 2015).

Teachers often focus on classroom pedagogy, science practices, and teacher content knowledge when engaging in teacher professional noticing (Kisa and Stein, 2015; Osmanoglu et al., 2015; Russ and Luna, 2013; Talanquer et al., 2013). Practicing and preservice teachers often focus on teacher pedagogy or pedagogical content knowledge (Kisa and Stein, 2015; Osmanoglu et al., 2015). Preservice teachers also noticed issues related to teacher action, such as management and communication with students (Osmanoglu et al., 2015). In addition to a focus on the teacher, teachers also attended to particular students' characteristics (Russ and Luna, 2013). For example, a teacher would capture a moment of student talk and reflect on this by explaining that this is a student who does not normally offer responses. Similarly, preservice science teachers also attended to student engagement related to specific practices, such as developing research questions, design and set up of experiences, constructing explanations from evidence (Talanquer et al., 2013).

Developing teacher professional noticing skills is a challenging endeavor (Jacobs et al., 2010), and these skills are not learned following same trajectory across teachers (Amador, et al., 2017; van Es et al., 2017; van Es and Sherin, 2008). Learning to engage in all three component skills of teacher professional noticing is challenging (Jacobs et al., 2010). Both preservice and in-service mathematics teachers engage in low frequencies of noticing (Dreher and Kuntze, 2015; Jacobs et al., 2010). However, in-service teachers are found to engage in noticing two-times the amount as preservice teachers (Dreher and Kuntze, 2015). Furthermore, preservice mathematics teachers less frequently make interpretive comments (Amador et al., 2016). Preservice secondary mathematics teachers develop in their noticing skills, but do so in different ways over time (van Es et al., 2017). Van Es and colleagues (2017) report that the LLfT course supported teachers in their elaborating skills (interpretation) but not in their attention to student thinking. Similarly, practicing elementary mathematics teachers first hone their skills of elaboration (van Es and Sherin, 2008).

To review, the key results from the cumulative literature on teacher professional noticing report that structured PD or courses on student thinking support development of teacher professional noticing skills. Teacher professional noticing component skills are challenging to develop over time. Each component skill in teacher professional noticing is developed differently, and individuals follow different trajectories in developing these skills. Additionally, the literature shows that teachers more often attend to classroom pedagogy, and spend more time describing and evaluating students' ideas.

Results in Responsive Teaching Studies

When looking holistically at the literature on responsive teaching, four major trends emerge from the responsive teaching studies' results:

1) Responsive teaching supports student learning.
2) PD or structured learning supports teacher responsiveness.
3) Teachers' focus is important in understanding responsiveness.
4) Content knowledge is important to teachers' responsiveness.

These results will be discussed in the following section in order to understand the current findings presented in the responsive teaching literature.

Teaching responsively allows teachers to better support their students' learning in the classroom (Coffey and Windschitl, 2016; Hammer et al., 2012; Levin et al., 2012). Teachers who teach responsively are able to attend to their students' thinking and respond to their students in ways that allow the student to work towards a deeper understanding of science (Hammer et al., 2012; Levin et al., 2012). Responsive teaching also supports students in engaging in science practices (Hammer et al., 2012). In order to support students in gaining a deeper understanding of science, science education must be high in rigor. Elementary science teachers use high rigor talk moves such as; open-ended questions, follow-up questions, and direct references to a recent class activity to support student learning (Coffey and Windschitl, 2016). Additionally, high rigor classrooms lead to increased student engagement, which supports student learning (Coffey and Windschitl, 2016).

Structured learning experiences or PD focused on student thinking helps to support teachers in becoming more responsive to student ideas (Levin et al., 2009; Lineback, 2014; Maskiewicz and Winter, 2012). Participation in PD supports teachers in their responsiveness to students' ideas in the classroom (Levin et al., 2009; Lineback, 2014) and the ability to adapt instruction based on responsiveness (Maskiewicz and Winter, 2012). More specifically, responsiveness increased after participating in PD focused on responding to students' ideas (Lineback, 2014). Similarly, after engaging in PD, responsive teaching supports teachers to adapt instruction each year based on their students' strengths (Maskiewicz and Winter, 2012). Teachers shift from having students plan, implement, and discuss their experiments, to students spending more time reasoning about their experiences and developing theoretical explanations. Levin and colleagues (2009) reported that when preservice teachers are not paying attention to student thinking, their focus is on classroom management (Levin et al., 2009). They further explain that attending to student thinking is an important first step in responsive teaching. Levin and colleagues (2009) continue by saying that not teaching novice teachers to attend to student thinking early in their careers, will result in continued practices that distract teachers from attending to student thinking.

How teachers focus their attention is important to understanding teacher responsiveness (Dyer and Sherin, 2015; Johnson et al., 2017). Practicing elementary teachers notice how students were interpreting an assignment about engineering, students' engagement in engineering, and student-to-student communication (Johnson et al., 2017). While engaging in instruction on engineering, teachers attend to the practices their students engage in, such as defining problems, designing solutions, and testing and refining designs. When considering the extent of a teacher's responsiveness, a quarter of a teacher's responses to their students were sensitive to student thinking (Pierson, 2008). However, almost half of a teacher's follow-up questions required low-level thinking from their students (Pierson, 2008). Reasoning plays a critical role in how a teacher responds to their students. Practicing secondary mathematics teachers engage in three types of instructional reasoning; making connections between specific moments of student thinking, consideration of the students' mathematical thinking and structure of the mathematical task, and developing assessments for student thinking (Dyer and Sherin, 2015).

Similar to teacher professional noticing, teacher content knowledge plays a role in responsiveness, namely in how a teacher chooses to clarify student thinking (Goodhew and Robertson, 2017). Teachers need to attend to student thinking in order to make connections between students' ideas, and then decide how to re-voice these ideas or probe further. Therefore, teacher content knowledge is critical in supporting the teacher to identify students' science ideas because without knowledge of the content, teachers will be unsure what content ideas are important to pick up.

Summary of Results

Both teacher professional noticing and responsive teaching studies reported that PD and other supports assisted teachers in developing the skills necessary to engage with student thinking. The results for both frameworks present the various things that teachers focus their attention on. In both teacher professional noticing and responsive teaching, teachers focus a large amount of their attention on the different pedagogical aspects related to the stimuli that they are observing. A key takeaway from the results of both frameworks is that teachers do and can develop in their ability to engage with student thinking, and that in doing so, teachers are creating learning environments that are more conducive to their students learning science.

Pedagogical Content Knowledge

Pedagogical content knowledge is a form of teaching expertise linked to classroom practice. Pedagogical content knowledge includes teachers' knowledge of the subject matter, pedagogy, and the classroom (Schneider and Plasman, 2011). Krepf and colleagues (2018) explain that pedagogical content knowledge includes four components, "knowledge of students' understanding, curricular knowledge, knowledge of instructional strategies, and conceptions of purposes for teaching subject matter," (pg. 46). More simply, pedagogical content knowledge is the knowledge that classroom teachers have about the subject matter they teach in order to make the content accessible to their students. In science, pedagogical content knowledge includes: "knowledge of students' thinking about science, science curriculum, science-specific instructional strategies, assessment of students' science learning, and orientations to teaching science," (Schneider and Plasman, 2011, pg. 534). When you consider the skills that pedagogical content knowledge includes, it makes sense that researchers believe that it is necessary for good teaching (Krepf et al., 2018).

Teacher professional noticing and responsive teaching studies have reported the importance of content knowledge (Goodhew and Robertson, 2017; Talanquer et al., 2015). These studies found that content knowledge is important for teachers to be able to identify important student ideas and evaluate their students' thinking. It stands to reason that teacher professional noticing and responsive teaching combine expertise in content knowledge and pedagogical content knowledge. Teachers must be able to gain pedagogical content knowledge through practice, but we can assist this development through PD. By assisting teachers in developing pedagogical content knowledge, teacher educators will help support teachers in paying attention to critical aspects of instruction that will support student learning.

Theoretical Framework Revisited

Below is the proposed theoretical framework that I have developed as a result of examining the literature on teacher professional noticing and responsive teaching. Richards and Robertson (2016) suggested that teacher professional noticing is an important precursor to responsive teaching, therefore, I have included horizontal arrows that move from left (teacher professional noticing) to right (responsive teaching). The literature for teacher professional noticing has implied the organizational order of attending, interpreting, and responding. Similarly, the literature for responsive teaching has implied the order of attention, identifying connections, and taking up and pursuing ideas. Colley and Windschitl (2016) describe responsive teaching as a cyclical process. Therefore, I have double-sided arrows between attention, identifying connections, and taking up and pursuing ideas. Additionally, due to Colley and Windschitl's (2016) description about the cyclical nature of responsiveness, I have drawn an arrow from taking up and pursuing ideas back to attention. While a cyclical nature between skills in teacher professional noticing has not been proposed in the literature, I also included reflexive arrows between noticing component skills and an arrow pointing from deciding how to respond back to attending. The reason that I included this cyclical nature for teacher professional noticing is because it seems reasonable to assume that how a teacher responds to a student idea will then influence what the teacher will next attend to. I have included the terms *ex situ* and *in situ* to reflect where the studies for each framework take place, outside the classroom in teacher professional noticing and inside the classroom for responsive teaching. While Richards and Robertson (2016) do not postulate in what way teacher professional noticing is a precursor to responsive teaching, I have provided horizontal arrows that move from attending to attention, interpretation to identifying disciplinary connections, and responding to taking up and pursuing ideas. Jacobs, et al. (2010) explain that attending is the most prominent skill in teacher professional noticing, while interpretation followed by responding are more challenging skills to develop over time. Goodhew and Robertson (2017) and Johnson, et al. (2017) explain that attention is the cornerstone to being able to engage in teacher responsiveness. Because attending is the most prominent skill in teacher professional noticing and attention to student thinking is critical to responsive teaching, I have suggested that developing skills in attending (noticing) may lead to growth in attention (responsive teaching). Moreover, the results from Jacobs, et al. (2010), Goodhew and Robertson (2017), and Johnson, et al. (2017) support the organization of the skills as depicted below.

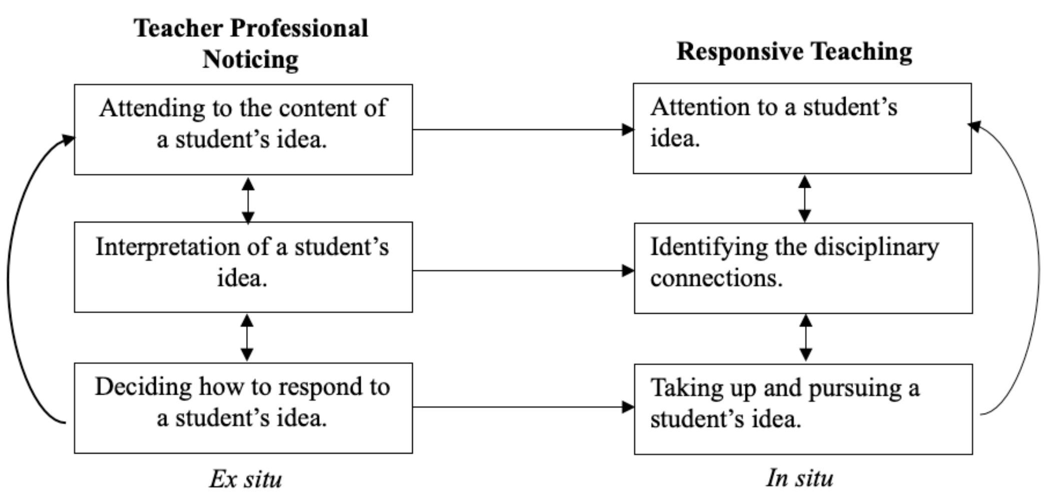

Figure 2.1: Proposed framework for the relationship between teacher professional noticing and responsive teaching.

Summary and Discussion

The goal of this literature review is to highlight current mathematics and science education studies that demonstrate the current state of the literature for both teacher professional noticing and responsive teaching. In doing so, I sought to highlight the primary methodologies and key findings in both teacher professional noticing and responsive teaching.

Methodologies

Researchers studying teacher professional noticing in mathematics and science education use a larger variety of methodologies than do researchers examining responsive teaching. In my review of the literature, I found that studies examining teacher professional noticing often use methods for understanding teacher attention outside of the classroom. A video-based course, LLfT, was used in three studies (Barnhart and van Es, 2015; Sun and van Es, 2015; van Es et al., 2017). By far the most used method for studying teacher professional noticing is a professional noticing task. This was used in both science studies (Talanquer et al., 2013; Talanquer et al., 2015; Osmanolgu et al., 2015) and one mathematics study (Jacobs et al., 2010). Professional noticing researchers also used discussion-based methods to examine the construct, in which researchers analyzed discourse teachers engaged in around classroom videos and instruction rehearsals (Benedict-Chambers, 2016). Interviews were also used to examine teacher professional noticing by Furtak and colleagues (2016) and Dreher and Kuntze (2015). However, the take-away from this is that each of these teacher professional noticing studies examined teachers' attention outside of the classroom and outside of instruction.

Studies examining responsive teaching in mathematics and science education do so within the context of the classroom and instruction. Analyses of classroom discourse is the most prevalent of the methods used to understand how teachers understand students' ideas in responsive teaching literature (Coffey and Windschitl, 2016; Hammer et al., 2012; Lineback, 2014; Maskiewicz and Winter, 2012; Pierson, 2008). Each of these studies examine the teacher and student talk that occurs within the classroom and use discourse analysis understand each talk-event. Other studies in the realm of responsive teaching use interview techniques to understand teachers' attention to their students (Dyer and Sherin, 2015; Johnson et al., 2017). Dyer and Sherin (2015) had their participants watch a video clip and were asked what they noticed. While Johnson and colleagues (2017) had a teacher record interesting moments and then reflect on these moments following instruction. Again, one of the primary takeaways from my review of this literature is that teacher professional noticing and responsive teaching research studies utilize different methodologies, and that these methodologies reflect the context in which the studies take place (inside or outside of the classroom).

Findings

Researchers who study professional noticing have found that teacher professional noticing skills are supported through PD or video-based courses (Barnhart and van Es, 2015; Jacobs et al., 2010; Kisa and Stein, 2015; Sun and van Es; 2015; van Es and Sherin; 2008). Despite being able to support teachers in being able to attend to, interpret, and decide how to respond to student thinking, researchers report that teachers often describe and/or evaluate the student thinking that is occurring in their classrooms (Amador et al., 2016; Sun and van Es, 2015; Talanquer et al., 2015). Researchers also found that teachers pay close attention to teacher pedagogy, science practices, and content knowledge (Kisa and Stein, 2015; Osmanoglu et al., 2015; Russ and Luna, 2013; Talanquer et al., 2013). These studies also report that developing attention to, interpretation of, and deciding how to respond to student thinking is challenging and does not develop in the same ways across teachers (Amador et al., 2017; Dreher and Kuntze, 2015; Jacobs et al., 2010; van Es et al., 2017; van Es and Sherin, 2008).

The studies focused on responsive teaching more closely reflect what is happening inside classrooms. At least three studies report that responsive teaching supports student learning in the classroom (Coffey and Windschitl, 2016; Hammer et al., 2012; Levin et al., 2012). Similar to the findings in teacher professional noticing, research studies in responsive teaching found that PD or other structured learning programs support teachers in development of their responsiveness to student thinking (Levin et al., 2009; Lineback, 2014; Maskiewicz and Winter, 2012). Responsive teaching studies also report that teachers pay attention to specific science practices (Johnson et al., 2017), engage in instructional reasoning (making connections between student ideas) (Dyer and Sherin, 2015), and measuring the sensitivity to student thinking (Pierson, 2008). Through my review of the literature, we also see that responsive teaching researchers also report that content knowledge is important to being able to teach responsively (Goodhew and Robertson, 2017).

Conclusion

To end, Richards and Robertson (2016) briefly address the debate regarding the connection between teacher noticing and responsive teaching. Teacher professional noticing is an important precursor to responsive teaching. Despite making this claim, there is no explicit evidence in the literature connecting these two frameworks. In this literature review, I have included my theoretical framework, which works to incorporate the literature from these two constructs to begin to make sense of and to illustrate the connections between teacher professional noticing and responsive teaching. The present study aims to contribute to the literature on teacher professional noticing and responsive teaching by beginning to illustrate the relationship between these two constructs. Additionally, this study contributes to the literature base by examining a group of teachers that are less frequently examined in the literature, experienced in-service secondary science teachers.

Chapter 3: Methods

Introduction

Richards and Robertson (2016) speculate that teacher professional noticing is a precursor to teachers' responsiveness to student thinking. In light of this, I used the results from two professional noticing tasks in combination with an analysis on teacher responsiveness to better understand the relationship between teacher professional noticing and teachers' responsiveness to student ideas. The current study examined this relationship. To accomplish this goal, I selected three secondary science teachers who participated in a five-year PD program, the Noyce Master Teacher Fellowship Project, which had an explicit focus on professional noticing of student ideas. Because I sought to understand the relationship between teacher professional noticing and responsiveness, I believed that it would be optimal to select teachers that we observed evidence of growth in their attention to student thinking, as measured through the professional noticing tasks.

This study used a combination of extant data, videos from the teachers' classrooms and teacher professional noticing tasks, and newly collected data. One interview was conducted with each participant around one of their existing classroom video submissions. I compared the growth in teachers' responsiveness as observed in their classroom videos to the growth in the teachers' professional noticing skills to understand the relationship between teacher professional noticing and responsive teaching. I used interview results to determine what teachers pay attention to when examining their own classroom teaching.

Context

This study took place in the context of a larger National Science Foundation funded Noyce Master Teacher Fellowship project that was conducted at a public university located in

Southern California from 2013-2018. Thirty-two participants were selected for the fellowship program, 16 mathematics teachers and 16 science teachers. All teachers taught at the secondary level at local middle and high schools. These teachers were selected after an intensive application process, where 126 applications were received and only 25% were accepted (Nickerson et al., 2019). The applicants were expected to demonstrate strong content knowledge, the ability to analyze student thinking through work samples, excellent teaching practices through video submission, and a disposition towards learning. Applicants were required to currently hold a master's degree or agree to completing a master's degree during the course of the PD program.

This PD program had an explicit focus on developing teachers' professional noticing in the context of the Next Generation Science Standards (NGSS), with the goal of developing the teachers' already exemplary teaching practices and to further teacher leadership skills. The PD program consisted of ten PD days per academic year, five days distributed from September through June and five consecutive PD meetings during the summer. During each day of PD, the participants worked with PD administrators from 8AM to 3:30PM. Between PD meetings, the teachers were given extensive homework assignments, not limited to: interviewing students, presenting at professional conferences, conducting an action research project, developing a phenomenon-based and NGSS-aligned unit, and meeting with their peers to observe others' teaching or receive peer feedback on their homework assignments.

Overview of Existing Data

A variety of data was collected throughout the course of the larger fellowship program, including classroom videos, professional noticing tasks, interviews, and artifacts from the PD sessions. Teachers were required to submit classroom video of their teaching each year, therefore, we have classroom video of each teacher for each of the five years of the PD program. Professional noticing tasks were also administered throughout the PD program. The genetics noticing task, designed after the task developed by Jacobs and colleagues (2010), was administered in May 2013, January 2016, and July 2018. These timepoints measure how the teachers engage in professional noticing before engaging in PD, after engaging in PD for 2.5 years, and after engaging in PD for 5 years. An additional professional noticing task, dealing with the concept of sound, was developed and administered in January 2016 and July 2018. Other data collected were interviews conducted in May 2018 by the PD administrators and artifacts stemming from the PD program, including homework assignments at various stages of completion.

Progression of Teacher Professional Noticing Skills

Genetics Professional Noticing Task

The genetics noticing task developed for the larger fellowship program. For this task, the teachers watched a short clip of a science classroom, where students working in small groups are making sense of the phenomenon of multiple alleles in a population (Carpenter and Romberg, 2004). The video depicts student groups working with a computer simulation, engaging in small group and whole group discussions, and creating their own models to explain the phenomenon they are observing in the computer simulation. The video also depicts how the teacher of that class engages in discussion with the student groups, probes students' thinking, and facilitates the whole-class discussion. This video was selected because it depicts students working together to problem solve, make sense of data, conduct an investigation, and create, use, and revise models. Because of these characteristics, the video clip provided the participants in this study the opportunity to notice a variety of different aspects about student thinking.

While watching the video, the teachers were unable to pause, rewind or replay the video. This was done to most closely mimic the in-the-moment decision making process that teachers encounter in their own classrooms. The teachers were also given student artifacts that included student-developed models of the phenomenon (Appendix A). The teachers were given the prompts below, one at a time. These prompts sought to elicit teachers' attending to, interpreting of, and responding to student thinking in the classroom. Teachers were not limited on the time given to complete this task but were given only one prompt at a time. Once the teachers completed one prompt, they turned this in, and then received the next prompt. The genetics task was administered three times in; May 2013, January 2016, and July 2018, marking the initial, mid, and final timepoints of the PD program. The prompts that the teachers responded to are as follows:

1. Everyone views instructional situations differently. What 3 aspects of this video did you find noteworthy?
2. Pretend that you are the teacher of this lesson.
   a. What is the most important thing for students to learn in this segment?
   b. Do you think they learned it? (Why or why not?)
   c. How might you assess the student understanding?
3. Please describe in detail and provide your reaction to what the different students did to make sense of the anomalous (to them) data they found (be as specific as you can).
4. Please describe and provide your reaction to what the teacher did as the students were making sense of the anomalous (to them) data.

Following completion of the tasks, the teachers' handwritten responses were blinded, transcribed, and the transcripts were entered in the data analysis software Dedoose (2019).

Before coding the data, three researchers completed the genetics task, discussed their responses, and then generated an initial coding scheme focused on aspects of student thinking that the research team expected in the teachers' responses. These codes as well as the final coding scheme used descriptive coding methods (Miles et al., 2014). This initial coding scheme was applied to the data and as the researchers progressed through coding, codes were added, revised, and/or removed using inductive coding techniques (Miles et al., 2014). This was accomplished through extensive discussion between the researchers. This process was performed for all participants from all three administrations. Each of the three researchers applied the final coding scheme in the dataset and compared code applications. All discrepancies were discussed until 100% agreement was reached.

Sound Professional Noticing Task

For the sound noticing task, each teacher was given three student-created models and corresponding explanations for why a wine glass breaks when a person sings into the glass (Appendix B). The teachers were given all of the student models at once, along with the first question for this noticing task. As each prompt was completed, the teachers turned in the completed prompt and the next prompt was given. Teachers were unable to go back to revise their responses to prior questions. The teachers were not limited in the amount of time they were given to complete the task. This task was administered twice, once in January 2016 and once in July 2018, marking the mid- and end-points of the larger study. The prompts that the teachers responded to are as follows:

The students completed a model to share their ideas about sound. Markers, poster paper and pencils were available for students to use. We have provided you with three students' models. The models included words and drawings. We have re-typed the students' writing when it wasn't adjacent to the picture. Examine the student work. Then, individually, please respond to the 3 questions.

1. Please describe in detail what you notice about each child's work.
    a. Susana
    b. Kenzie
    c. Amy
2. Explain in detail what you believe you have learned about each child's ideas/understanding about sound.
    a. Susana
    b. Kenzie
    c. Amy
3. Pretend you are the teacher of these students. What instructional decisions would you make for the next lesson(s). Explain your rationale. Why would you decide to do this?

Teachers' responses were blinded, transcribed and uploaded into Dedoose (2019). Like the genetics noticing task, a base coding scheme was developed using descriptive codes (Miles et al., 2014). This was performed by one of the researchers. After the base coding scheme was developed, two researchers coded the data and worked together to reach full consensus on the codes applied to each response. This process was inductive, included adding, removing, and revising codes from the initial coding scheme (Miles et al., 2014). The sound noticing tasks were coded by two researchers, however, a third researcher participated in the coding meetings to help reach a consensus.

Participants for the Current Study

I selected three teachers from the larger Noyce Master Teacher Fellowship project, described above. The larger fellowship program began with sixteen science teachers and ended with fourteen science teachers due to attrition. Additionally, two more teachers took more administrative positions during the program and were therefore not actively teaching. On average, these fourteen teachers had 13.2 years of teaching experience by year five of the fellowship program.

My initial pool of teachers consisted of the 12 teachers who participated in the full length of the fellowship program and remained teaching in the classroom for these five years. Out of these 12 teachers, I reviewed the project video data archive and eliminated any teachers from the overall data pool with missing video and/or with video in which the audio quality is poor. Any teachers with missing video submissions were removed from my participant pool. From this subset of teachers, I considered the results from the genetics and sound noticing tasks. As a reminder, my goal was to identify three teachers where the evidence showed growth in teacher professional noticing skills, as measured through the genetics and sound noticing tasks. From this analysis, three teachers were selected and invited to participate in my study. These teachers were given the following pseudonyms: Mrs. Hollander, Mrs. Packer, and Mr. Sanchez. The results of the teacher professional noticing tasks that allowed me to select these participants will be described in detail in Chapter 4.

Two major goals of this study were: 1) to provide empirical evidence about the relationship between the development of teacher professional noticing skills and teacher responsiveness to student thinking, and 2) to provide evidence for whether redirections can be used to monitor teachers' responsiveness over time and across teachers. I believe that by selecting three teachers that demonstrate a clear development in teacher professional noticing skills would increase the likelihood in being able to understand how developing professional noticing skills is related to development in teacher responsiveness.

Classroom Videos

Throughout the duration of the PD program, teachers were asked to submit whole-classroom videos of their teaching. These videos included annual submissions at the end of each academic year of the study: 2013-14, 2014-15, 2015-16, 2016-17, and 2017-18. Teachers were asked to submit video that was representative of their daily teaching practices, and each teacher was required to submit these annual videos. These videos are approximately one hour long. The content of the video ranges from small-group work, lectures, laboratory activities, etc. The teachers in the fellowship program were given iPads for recording classroom videos and the teachers wore a mic so that the teachers' speech would be heard clearly. The videos vary in relation to the content area being taught (biology, chemistry, earth science, etc.) and the grade level being taught (middle and high school). These videos were analyzed during the larger grant for the external evaluator but were not examined using the lenses of teacher professional noticing and teacher responsiveness to student thinking prior to the present study

Discourse Analysis: Redirections

I used discourse analysis, more specifically redirections (Lineback, 2014), to examine teachers' responsiveness to student thinking in the classroom videos. The development of the redirection emerged from a larger research project with the goal of promoting and supporting elementary and middle school teachers in teaching inquiry-based science in their classrooms (Lineback, 2014). As part of the larger study, the researcher developed curricular modules in which room was explicitly made for teachers to be responsive to student thinking as their students' ideas emerged during discussion activities. Lineback's (2014) article focuses on one curricular module on the water cycle. The module comes with curricular materials that explicitly give the teacher the freedom to choose which instructional paths to take based on the emergence of student ideas. For the purpose of this smaller study, Lineback (2014) selected one participant who stood out. This teacher, Mrs. Miller, described her teaching prior to the study as content-driven and she used guided activities to support her students through the scientific method. Mrs. Miller was a fifth-grade teacher with 20 years of teaching experience, at the time of the study. Lineback (2014) engaged in careful examination of Mrs. Miller's discourse while Mrs. Miller taught the water cycle module. Through this examination, the author identified specific moves that Mrs. Miller used to shift, or attempt to shift, her students' attention during whole-class discussion. Through a constant comparative method, Lineback (2014) developed categories for the different types of redirections that Mrs. Miller used to shift her students' attention. After the coding scheme was developed, it was applied to three additional fifth-grade teachers to determine its reliability.

The first step in Lineback's coding process was determining if a teacher's comment or question is a redirection or not (Figure 3.1). If the comment or question is a redirection, the next step is to determine what type of redirection the statement is, either an activity redirection or a focus redirection (Figure 3.1). Attempts to shift students' activities are considered activity redirections, and attempts to shift students' focus from an activity or phenomenon to another are considered focus redirections (Figure 3.1). An example of an activity redirection would be inviting the students to shift from discussing a phenomenon to designing an investigation around that phenomenon. Whereas an example of a focus redirection would be inviting students to shift from discussing what happened during a given phenomenon to discussing the meaning of a related scientific term.

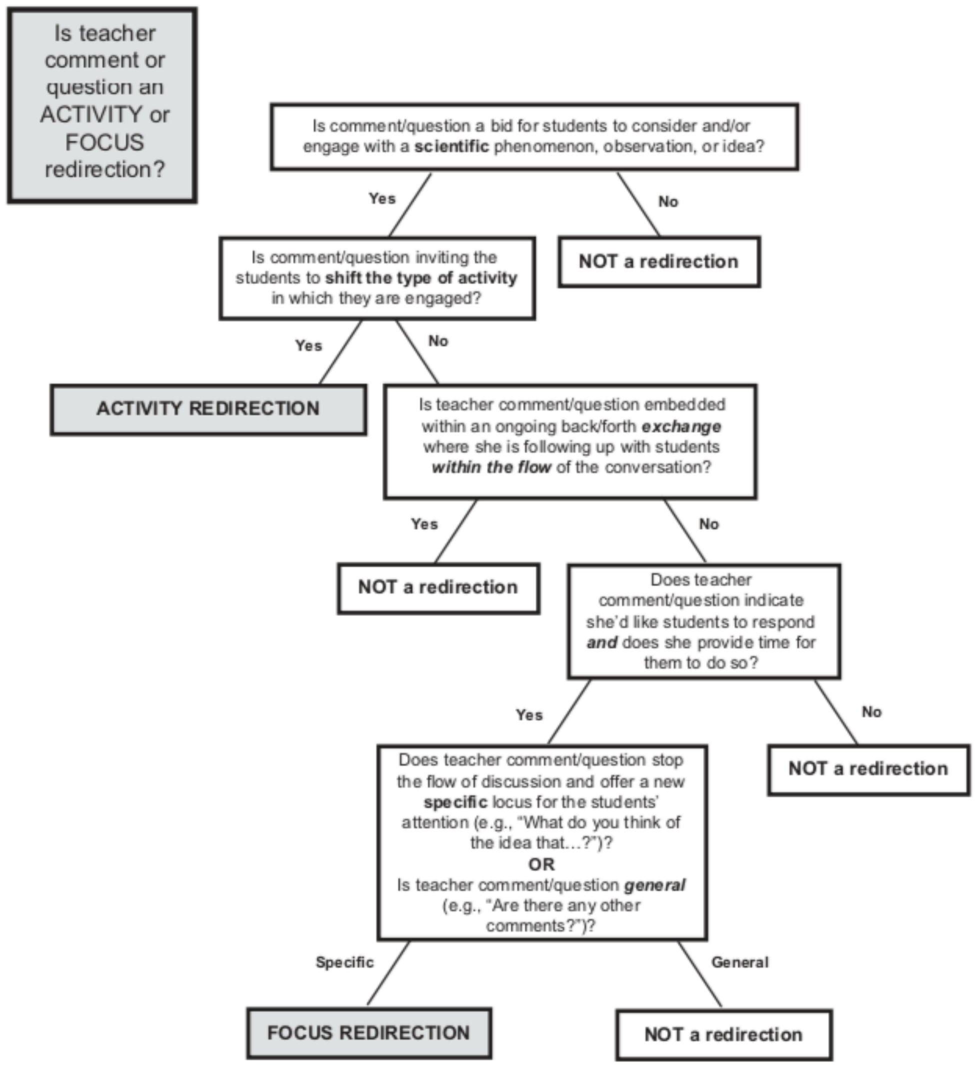

Figure 3.1: Lineback's (2014) flowchart in deciding whether a teacher comment or question is: 1) a redirection or not, and 2) an activity or focus redirection.

Lineback's (2014) redirections coding scheme is summarized in Table 3.1. It is first broken down to activity redirections and focus redirections (Table 3.1). Activity redirections are then sorted into two categories, either responsive to a student's comment or not responsive to a student's comment (Table 3.1). Focus redirections are sorted into three categories; responsive, delayed responsive, and not responsive (Table 3.1). A focus redirection that is responsive is clearly connected to a student's comment in the same, immediate episode. Delayed responsive is clearly connected to a student's previous comment (a different episode or lesson entirely), and not responsive is a comment not connected to a student's idea.

Table 3.1: This table outlines Lineback's (2014) redirections framework. The redirections framework is separated into two major categories: activity redirections and focus redirections. Activity redirections have two classifications, A1 and A2. Focus redirections have three major classifications, F1, F2, and F3. F1 is further broken down into F1-TRM, F1-REP, F1-MIN, F1-MOR, and F1-CON. The table provides a brief definition for each category of redirection.

	Code	**Description**
Activity Redirection	A1	Teacher's bid is clearly responsive to student comments/ideas
	A2	Teacher's bid is NOT clearly responsive to student comments/ideas
Focus Redirection	F1	Responsive: Redirection is clearly grounded in and/or connected to student comment/idea(s) raised during the last exchange
	F1-TRM	Requests students to explain, exemplify, or identify a term
	F1-REP	Requests student to repeat a comment made previously
	F1-MIN	Is minimally or tangentially related to student comment(s)
	F1-MOR	Requests students extend/elaborate student comment(s) in a specific way
	F1-CON	Requests the students consider / reason about student comment(s)
	F2	Delayed responsive: Redirection is disconnected from student comments during the last exchange sequence; however, it invites the students to revisit, discuss, and/or elaborate phenomena considered, ideas contributed, or questions previously raised
	F3	Not Responsive: Redirection does not appear connected to student comments/work

Lineback (2014) defined a redirection as a "teacher's bid to shift, refocus, or redirect the attention of the class from one scientific phenomenon/question/activity to another," (pg. 12). Using this lens, I examined only the moments in classroom instruction in which whole class discussion was taking place. Segments in the classroom videos when students were engaging in an individual task or discourse occurring during small groups were not transcribed or coded for, because they go beyond the scope of the redirection framework (Lineback, 2014). Transcripts were divided into talk turns, and only talk turns where the teacher engages in a redirection will receive the corresponding redirection code.

For my analysis, I used the qualitative analysis software, MAXQDA Analytics Pro (VERBI Software, 2016). MAXQDA allows you to upload a video and create a corresponding transcript that links timepoints in the video file to timepoints in the transcript. This was an important characteristic of the analytic software I used because Lineback (2014) explains that both facial expressions and body movement can be indicative of a redirection.

I started my analysis of classroom video using deductive coding (Miles et al., 2014). My starting set of codes were Lineback's (2014) coding scheme as reported. Because Lineback's (2014) coding scheme was generated in the context of an elementary science classroom, after initial application I revised this coding scheme to account for the teacher-student interactions in a secondary science classroom. This revision took place after the full dataset was initially analyzed. While engaging in my initial application of codes, I took notes on the different not responsive activity redirections that teachers engaged in. These were not accounted for in Lineback's (2014) coding scheme. After identifying five additional codes that more specifically identify the types of not responsive activity redirections that were present in my data, I applied the revised coding scheme to my dataset. Lineback's (2014) coding scheme, adapted for my study, will be presented in Chapter 4. I coded the entire dataset and a second coder was recruited to double-code 20% of the dataset. Our original agreement was 85%, and after discourse on discrepancies, we reached 100% agreement of code application.

Interviews

In addition to my analysis of the teacher professional noticing tasks and the redirection analysis of classroom videos, I also conducted and analyzed interviews that centered around each teachers' own classroom videos. The goal of conducting semi-structured interviews was to determine what teachers pay attention to when watching their own classroom instruction. Some questions that I asked myself when analyzing the classroom video were:

1) In what ways do teachers pay attention and respond to student thinking?

2) Do teachers primarily focus on their students' thinking and practices, or do they focus their attention on other aspects of instruction, like their own practice?
3) Do teachers note shifts in activities or focus as important instructional moments?

Due to the Coronavirus pandemic, I was unable to conduct my interviews using my originally planned methodologies. Teachers were teaching their students virtually, therefore, conducting traditional classroom observations and video collection was not possible. Therefore, I adapted my original methodologies which closely reflected the Colestock and Sherin (2016) study.

For each teacher in my study, I identified one classroom video that I had analyzed for my redirections analysis to watch during our semi-structured interviews. Each teacher watched a video of their own teaching. Out of the five videos I had for each teacher, I sought to identify one video that incorporated the most student-teacher interactions. My reason for selecting videos with a large amount of student-teacher interaction was to increase the opportunity that my participants could observe their responsiveness to student thinking.

Our interviews took place online, using Zoom (Version 5.4.7) during the Fall of 2020 and I allotted two hours of time for each interview. To begin the interview, I instructed the teacher that I would be sending them one of their classroom videos. I explained that we would watch the video from start to finish, and asked that they pause the video when they found an interesting moment of instruction. The teacher shared their screen with me and we watched the classroom video together. By allowing the teacher to play the video on their computer, they were able to press pause and play when needed. After pressing pause I presented two prompts, which led the conversation around each moment the teacher tagged as interesting. The prompts I raised were:

1) Explain why you tagged this moment as interesting or important.

2) Explain the student thinking that is taking place during this moment.

The protocol for tagging interesting or important moments of instruction and the two questions above were described in the interview protocol of Colestock and Sherin (2016). My participants and I repeated the process of watching the classroom video, the participant pausing on interesting moments, engaging in discourse, then continuing to watch the video, until the whole classroom segment had been viewed.

While I interviewed my participants, I took detailed notes on the moments in which the teacher chose to pause the video and their reasoning behind selecting that instructional moment. The interviews were also recorded using the Zoom application and automatically transcribed through Zoom. My notes allowed me to begin my analysis of the interviews that I conducted. I sought to identify themes for the reasons the participants paused their classroom video and why they considered the moment interesting. Colestock and Sherin (2016) identified six approaches in which teachers attend to student thinking: indicator of learning, problems to be addressed, resources to be collected, foundations to build on, message to be deciphered, and products of a process. I used these approaches as a baseline for categorically sorting the reasons for why each teacher paused their classroom video. The categories that I identified will be discussed in detail in Chapter 4.

Data Analysis

My data analysis included both qualitative and quantitative analyses. In Robert Stake's (1996) book, *The Art of Case Study Research*, he says, "the quantitative side of me looked for the emergence of meaning from the repetition of phenomena. The qualitative side of me looked for the emergence of meaning in the single instance," (p. 76). This quotation illustrates the importance of looking both quantitatively and qualitatively to best understand the entire picture.

Similar to the point in this quote, the goal of my quantitative analysis is to establish and understand the patterns or trends in the data, whereas my goal for the qualitative analysis is to understand and describe responsiveness in secondary science classrooms. Due to the small sample size of my study, I did not run any statistical analyses that would indicate significance.

Quantitative Analyses

Generating and using coding schemes to analyze the teacher professional noticing tasks and the classroom videos allowed me to quantify the number of codes applied to each task response and transcript, allowing me to draw comparisons across time and across teachers. By conducting these coding analyses, I was able to identify how individual teachers shift in their teacher professional noticing skills and responsiveness to student thinking throughout the five-year PD program, as well as draw comparisons across the three participants in relation to teacher professional noticing and responsive teaching.

As previously described, I had already conducted an analysis of the teacher professional noticing tasks. This analysis was conducted to identify which participants in the larger PD program would be invited to participate in the present study. Through this analysis, I considered how the participants changed in relation to their; attending, interpretation, and response to student thinking across the two professional noticing tasks. I also considered what the teachers focused their attention on, student thinking (represented by content and practice in my coding scheme) or teacher moves and classroom features (TMCF). Individuals who paid more attention to student thinking were prioritized over participants who paid more attention to TMCF. Individuals whom I had evidence for growth in one or more skills were prioritized for selection in comparison to individuals who demonstrated lower evidence of growth. My analysis of the teacher professional noticing tasks allowed me to understand how teachers shifted in engaging in the teacher professional noticing skills over time, as well as compare these shifts across teachers.

After coding the classroom videos for my redirections analysis, I sought to address the following questions:

1) Does teacher responsiveness to student thinking shift over the course of five years?
2) How does teacher responsiveness to student thinking compare when looking across the data for three different teachers?
3) How do the results in my professional noticing analysis compare to the results in my responsive teaching analysis?

Because of the size of my dataset, I cannot confidently run statistical analyses on my quantitative data. Instead, the quantitative results of this study help to provide empirical evidence as to whether studying and practicing teacher professional noticing relates to higher responsiveness to student thinking in the classroom. These quantitative results also help to illustrate the types of redirections that secondary science teachers engage in, providing evidence for teacher responsiveness to student thinking, and shifts in this responsiveness over the course of an extended PD program.

Qualitative Analysis

In conducting my analysis, I developed case studies for each of the three teachers in my study. Stake (1996) explains that direct interpretation and categorical aggregation are two important analytical strategies that researchers can use when conducting case studies. For each case, I described the results from coding the teacher professional noticing tasks and the classroom videos using redirections. I also presented the themes that I identified in my one-on-one interviews with each teacher. I first used my categorical analyses to understand and illustrate the shifts that teachers made in relation to their teacher professional noticing skills and responsiveness. I then selected direct quotes from the noticing tasks, classroom videos, and interviews to elaborate on my findings. By including the teachers' quotes, I was able to emphasize particular points as well as draw relationships between noticing and responsiveness more clearly.

Following my quantitative analysis of each data source, I present my qualitative analysis. The goal of my qualitative analyses was to illustrate the trends described in my quantitative analyses and portray each teachers' voice. I used my qualitative data to show how; 1) teachers develop in their growth of particular teacher noticing skills over the course of the five-year PD program, 2) particular teacher comments represent activity and focus redirections, and 3) teachers describe and analyze their own classroom videos.

By coding my data, I was able to categorically analyze my results. For my teacher professional noticing tasks, I was able to categorize teachers' responses into one of the three skills (attending, interpreting, or responding) and categorize whether the response represented student thinking (content and practice) or TMCF. For my analysis of responsiveness, coding for redirections allowed me to categorize my data into responsive or not responsive activity redirections, and responsive, delayed responsive, or not responsive focus redirections. These categories supported me in providing evidence for how teachers grew in their teacher professional noticing skills and responsiveness over time. These categories also allowed me to compare trends across the three participants.

The categorical data, however, was limited in being able to illustrate the relationship between my results of teacher professional noticing and responsive teaching. I needed to review the teachers' responses to the teacher professional noticing tasks in order to find the minute details necessary for illustrating the relationship between these two constructs. By examining what the teacher wrote, I was able to observe how each teacher advanced in their ability to analyze particular aspects of science practice and instruction. It was in these details that the relationship between teacher professional noticing and responsive teaching began to appear. I compared the descriptive advances teachers made on their teacher professional noticing task to their redirections to begin to illustrate the relationship between frameworks.

Summary

The goal of the present study was to understand the relationship between teacher professional noticing and responsive teaching in secondary science teachers. I conducted longitudinal analyses on responses to teacher professional noticing tasks and classroom videos. These analyses allowed me to understand how teachers develop in their teacher professional noticing and responsive teaching over time and across participants. My qualitative data supported me in illustrating the changes that I observed. Additionally, I used interviews to gain insight into how teachers view their own classroom teaching. Below is a table that summarizes each research question and the data that I used to address each question.

Table 3.2: Summary of research questions and data collected in order to address each question.

Research Questions		**Data Used to Address Research Question**
Question 1	In what ways does teachers' responsiveness to student thinking shift during an extended professional development program with a focus on students' scientific thinking?	• Redirections (classroom video analysis)
Question 2	In what ways do teachers grow in relation to their professional noticing skills and their responsiveness to student thinking, during the course of a five-year professional development program focused on student thinking?	• Professional noticing tasks (genetics and sound) • Redirections (classroom video analysis)
Question 3	During instruction, what instructional moments do teachers identify as critical moments, and how do these moments relate to teachers' responsiveness to student thinking?	• Analysis of interviews

Chapter 4: Results

Introduction

The current study had three phases: 1) examine participants' change in teacher professional noticing over the course of a five-year professional development (PD) program, 2) examine participants' change in responsiveness over the course of a five-year PD program, and 3) examine what teachers pay attention to during observation of their own teaching. I will begin by giving a brief overview of my study's results, presenting the data as a whole. Then I will present individual case studies of each participant in order to create a picture of how these individuals developed in their professional noticing and responsiveness to student thinking over time.

Teacher Professional Noticing Overview

For the first phase of this study, two professional noticing tasks were administered, a genetics task using video and a sound noticing task using student work samples. The genetics task was administered in 2013, 2016, and 2018, while the sound noticing task was administered in 2016 and 2018. With the help of Noyce Science research team, I developed a coding scheme that accounts for all three professional noticing skills; attending, interpreting, and responding. Additionally, the coding scheme accounts for student thinking through "content and practice" (CP) identifiers and all other noticings were identified as "teacher moves and classroom features" (TMCF) (Table 4.1).

Table 4.1: Table represents overarching code categories for the genetics and sound teacher professional noticing tasks. Attending, interpreting, and responding are coded for content and practice, and teacher moves and classroom features. Attending is further broken down into high and low levels.

Attend	**Interpret**	**Respond**
Content & Practice-High	Content & Practice	Content & Practice
Content & Practice-Low		
Teacher Moves & Classroom Features-High	Teacher Moves & Classroom Features	Teacher Moves & Classroom Features
Teacher Moves & Classroom Features-Low		

I found that in the codes accounting for attending, teachers made statements that I considered as high or low level. It was clear through the analysis that the attending codes needed to be differentiated by levels because teachers were making statements that were more advanced in some cases, and less advanced in others. Table 4.2 below includes examples for each coding category included in the noticing analysis, the primary purpose of this table is to illustrate the ways in which each coding category differs.

Table 4.2: Example codes provided for each major code category for the noticing task analysis. Example codes are provided for all three skills; attending, interpreting, and responding. As well as accounting for varying degrees of these codes; content and practice (student ideas) and teacher moves and classroom features.

Major Code Category	**Examples of Specific Codes Applied to the Data**
Attend-CP-High	Students use models to predict or answer questions
Attend-CP-Low	Students use models
Attend-TMCF-High	Teacher encourages students to revise model
Attend-TMCF-Low	Teacher puts students in groups
Interpret-CP	Students don't understand basic inheritance
Interpret-TMCF	Teacher asks question to shift student understanding
Respond-CP	Teacher provides students with the opportunity to observe new phenomena
Respond-TMCF	Teacher offers feedback to promote learning

The analysis of the two professional noticing tasks helped me to identify which of the 16 participants in the PD program I would invite to participate in the current study. I sought to identify three participants who demonstrated increases in their professional noticing skills over the course of the five-year PD program. I have given these teachers the following pseudonyms; Mrs. Hollander, Mrs. Packer, and Mr. Sanchez.

Responsive Teaching Overview

During the five-year PD program, all participants were asked to submit classroom videos for each academic year; 2013-14, 2014-15, 2015-16, 2016-17, and 2017-18. After selecting the participants for the current study, I pulled their videos from our PD data archive. The classroom videos ranged in length from 36 minutes to 1 hour and 3 minutes. The total time of video I analyzed for each participant was; 245 minutes and 14 seconds for Mrs. Hollander, 254 minutes and 32 seconds for Mrs. Packer, and 242 minutes and 41 seconds for Mr. Sanchez. In order to code for teacher responsiveness in each video, I used Lineback's (2014) redirections framework, which I adapted. My adapted coding scheme included classifications for activity redirections that were not responsive to students' ideas (Table 4.3). My fully adapted redirections codebook can be found in Appendix C.

Table 4.3: Major code categories for activity and focus redirections are identified. Corresponding codes applied to the dataset that differentiate responsive verses not responsive. Not responsive activity codes and responsive focus codes are further identified.

Major Code Category	Examples of Specific Codes Applied to the Data
Activity Redirection – Responsive	A1
Activity Redirection – Not Responsive	A2
	A2 – Whole class discussion
	A2 – Individuals develop/revise explanations/models
	A2 – Individuals complete surface level tasks
	A2 – Small group/partner discussion
	A2 – Observation/investigation as whole class or in groups
Focus Redirection – Responsive	F1
	F1 - TRM
	F1 - REP
	F1 - MIN
	F1 - MOR
	F1 - CON
Focus Redirection – Delayed responsive	F2
Focus Redirection – Not responsive	F3

I coded the entire dataset and a second coder was recruited to code 20% of the dataset. We obtained 85% agreement between the two coders and discrepancies were discussed until 100% agreement was reached.

Interviews Overview

I conducted one semi-structured interview with each participant in the Fall of 2020. These interviews centered around one classroom video selected from my dataset. I selected the following videos to watch during the interviews; 2015-16 for Mrs. Hollander and Mrs. Packer, and 2016-17 for Mr. Sanchez. I selected these specific videos because they included the most teacher-student interaction, which I expected would provide the participants with the most opportunity to reflect on their teacher professional noticing skills and/or responsiveness to students in their classrooms. The lengths of the interviews were; one hour and 27 minutes for Mrs. Hollander, one hour and 55 minutes for Mrs. Packer, and one hour and 57 minutes for Mr. Sanchez.

The goal of my analysis for the interviews was to determine what teachers pay attention to when they watch and analyze their own teaching. Upon initial analysis of the interviews, I found that the teachers did not identify redirections as critical moments of instruction. Further, three major themes became apparent in the interviews: 1) evaluation of teaching practices, 2) why specific teaching decisions were made, and 3) attention to content taught/learned.

Mrs. Hollander

Mrs. Hollander is a high school chemistry teacher who had 1.5 years of teaching experience at the beginning of our PD program in 2013. By the end of the PD program, Mrs. Hollander had 6.5 years of teaching experience. At the time of the interview in 2020, Mrs. Hollander had 8 years of teaching experience. Mrs. Hollander holds a bachelor’s degree in biology and a master’s degree in genetics.

Mrs. Hollander’s Teacher Professional Noticing Trends

I selected Mrs. Hollander as one of my study participants because of the growth I observed in both of the professional noticing tasks. First in the genetics noticing task (Table 4.4), Mrs. Hollander increased in her attention to CP from 2013 to 2018, for both high level codes (0 to 4) and low level codes (3 to 5). Mrs. Hollander also increased in her ability to interpret CP from 2013 to 2018 (0 to 6). I also noted and increase from 2013 to 2016 (initial to midpoint) in attending TMCF high level (1 to 4). Interpreting TMCF did not change across all three samplings.

Table 4.4: Genetics noticing task results for Mrs. Hollander broken down by each major code category and year of sampling. Attending and interpretation are coded for.

Genetics Noticing Task (Video with Supplementary Work Samples)						
	At-CP High	At-CP Low	At-TMCF High	At-TMCF Low	Int-CP	Int-TMCF
2013	0	3	1	6	0	2
2016	2	5	4	2	1	2
2018	4	5	1	4	6	2

Figure 4.1 below includes a portion of Mrs. Hollander's response to the genetics teacher professional noticing task. I wanted to highlight Mrs. Hollander's responses in 2013 and 2018 in order to show how Mrs. Hollander develops over the course of the five-year study. In 2013, Mrs. Hollander uses more low-level skills. She discusses to content and talks about students reaching conclusions. In 2018, Mrs. Hollander increases the complexity of her response. She talks about using models and data to develop an explanation that is supported by evidence. This latter response is richer, and demonstrates that Mrs. Hollander is thinking more about the complex science practices that the students in the video were engaged in.

Pretend that you are the teacher of this lesson. A) What is the most important thing for students to learn in this segment? B) Do you think they learned it? (Why or why not? C) How might you assess the student understanding?	
2013	**2018**
A) I think it is how different sets of data can lead to conclusions and specifically what combinations of alleles can produce different phenotypes.	A) The students were using a model to create data to explain their hypothesis. The students had an idea about the inheritance pattern and then tried a cross to see if it supported or didn't support their data.

Figure 4.1: Mrs. Hollander's responses from 2013 and 2018 to a portion of the interpreting prompt of the genetics teacher professional noticing task.

In the sound noticing task (Table 4.5), Mrs. Hollander increased in her ability to attend to high level CP (15 to 27) and her ability to attend to low level TMCF (3 to 4) from 2016 to 2018. I also noticed growth in Mrs. Hollander's interpretation of TMCF in the sound noticing task (0 to 3) from 2016 to 2018. I found decreases from 2013 to 2016 in attending CP (low level, 19 to 15) and responding CP (5 to 2). I observed no change from 2016 to 2018 in attention TMCF (high, 0 codes), interpretation CP (6 codes), and responding TMCF (5 codes).

Table 4.5: Sound noticing task results for Mrs. Hollander broken down by each major code category and year of sampling. Attending, interpreting, and responding are coded for. Sampling occurred in 2016 (middle) and 2018 (final year of PD program).

Sound Noticing Task (Student Work Samples)								
	At-CP High	At-CP Low	At-TMCF High	At-TMCF Low	Int-CP	Int-TMCF	Resp-CP	Resp-TMCF
2016	15	19	0	3	6	0	5	5
2018	27	15	0	4	6	3	2	5

As I previously stated, I selected Mrs. Hollander to participate in this study due to her growth across both tasks in both attending and interpretation, and her growth in attending to CP high level. This being said, I did not find evidence of growth in the same way across both noticing tasks for Mrs. Hollander. I found that Mrs. Hollander increased only in attending CP (high level) for both noticing tasks. Another trend that I noted is that Mrs. Hollander increased in her noticing skills in relation to student thinking (CP) for the genetics task, while in the sound noticing task, Mrs. Hollander primarily increased in her attending to TMCF.

I also noted that in some skills, the total number of codes decreased from the initial to final sampling. In response to the genetics professional noticing task, Mrs. Hollander decreased in her attention to TMCF (high and low level) from 2013 to 2018. This could be explained by her increase in attention to CP (high and low level) from 2013 to 2018 in the genetics task. This means Mrs. Hollander did not necessarily attend to more things in 2018 than in 2013, rather she attended to more student thinking in 2018.

Mrs. Hollander's Responsiveness to Student thinking

I measured participants' responsiveness to student thinking using redirections. The tables below summarize the redirection codes that were applied to Mrs. Hollander's classroom transcripts across our five-year PD program. The tables below represent the activity redirections (Table 4.6) and focus redirections (Table 4.7) that were applied to Mrs. Hollander's classroom videos over the course of the five-year study. Before describing the results of my redirections analysis, I will briefly describe what occurred during each classroom video submitted.

In the first year of the study (2013-14), Mrs. Hollander leads her class through whole class discussions and investigations around fats and oils present in foods. In this video, the student groups select different types of snack chips to extract the oils from to determine which chip is likely the healthiest. The investigation is broken up by frequent whole class discussions and a few small group chats. In 2014-15, Mrs. Hollander focuses on what makes strong claims, evidence, and reasoning. During this video, she leads her students through whole class discussions around claim-evidence-reasoning and reading an article around beta-carotene in carrots supporting eyesight. The students work in groups to find evidence via internet searches, supporting or refuting the claim that beta-carotene supports eyesight. In 2015-16, Mrs. Hollander works with her class to consider the strengths and weaknesses of different molecular models.

They discuss the different models that they have been presented with over the course of the year. These discussions occur in whole class and small group settings. In the fourth year of our PD program (2016-17), Mrs. Hollander's classroom video focuses on elements in the periodic table, atomic number, mass number, protons, neutrons, electrons, and isotopes. Students work to complete a worksheet around these concepts on their own, while discussing problems posed on the worksheet in their table groups and through whole class discussion. In the final video (2017-18), students engage in an investigation around bonding. The students complete a graphic organizer allowing them to record their observations and develop claims-evidence-reasoning about the bonding characteristics of different liquids.

Table 4.6: Activity redirections data table for Mrs. Hollander's classroom videos across all five years of the PD program. Total number of codes for each activity redirection code are identified for each year. Cells without a code count are shaded in grey.

Code	**2013-14**	**2014-15**	**2015-16**	**2016-17**	**2017-18**
A1 - Responsive					
A2 – Whole class discussion	4	4	3	3	4
A2 – Individual develop/revise explanations/models					
A2 – Individual complete surface level work				1	
A2 – Small group/partner discussion	2	2	2	2	4
A2 – Observation/investigation as whole class or groups	2	3			1

Mrs. Hollander has no responsive activity codes (A1) across all five years of the study (Table 4.6). This suggests that Mrs. Hollander is minimally to student thinking, evidenced by activity redirections. I identified evidence of a number of not responsive activity redirections (A2) in Mrs. Hollander's classroom videos. Mrs. Hollander has evidence of the following not responsive activity redirections (A2); whole class discussions, individual's completion of surface level tasks, small group or partner discussion, and observation or investigation as a whole class or in groups. These codes are representative of the activity shifts that occurred in Mrs. Hollander's classroom, not responsive to student thinking. Mrs. Hollander consistently engages her students in whole class discussion (3 or 4 codes per year) and small group discussion (2 codes from 2013-17 and 4 in 2017-18) across all five years of the PD program.

An example of a not responsive activity redirection for whole class discussion is the following quote from Mrs. Hollander's 2017-18 classroom video, "Okay, so I'm hearing the talking slow down. So, I'm wondering if we've got to the answers here. Okay, so based on our data for station two which liquid do we think is the most cohesive? Yeah, Jessie? (Hollander 2017-18, 42:54). Prior to this excerpt, students are conducting investigations in their groups, Mrs. Hollander is shifting her students from engaging in investigations to a whole class discussion. Because Mrs. Hollander is not redirecting the activity as a result of a student idea, this example is considered not responsive.

In addition to consistently engaging in whole class discussion, Mrs. Hollander also consistently engages her students in small group or partner discussion (2 codes). However, in the final classroom video, Mrs. Hollander increases in the instances that she engages her students in small group or partner discussion to 4 codes in 2017-18. Mrs. Hollander also engages her students in observations of phenomena or science investigations in 2013-14, 2014-15, and 2017-18. These results show Mrs. Hollander engages her students in a variety of activities.

Table 4.7: Focus redirections data table for Mrs. Hollander's classroom videos across all five years of the PD program. Total number of codes for each focus redirection code are identified for each year. Cells without a code count are shaded in grey.

Code	2013-14	2014-15	2015-16	2016-17	2017-18
F1 - TRM		1		2	
F1 - REP					
F1 - MIN	1				1
F1 - MOR					
F1 - CON					
F2 – Delayed responsive					1
F3 – Not responsive		2	1		

In contrast to the results of my activity redirections analysis, I found that Mrs. Hollander engages in responsive focus redirections (F1). I found that Mrs. Hollander engaged in two types of F1 redirections, F1-TRM (focus redirection – terminology) in 2014-15 (1 code) and 2016-17 (2 codes), and F1-MIN (focus redirection – minimally responsive) in 2013-14 (1 code) and in 2017-18 (1 code). While my activity redirection analysis did not provide evidence that Mrs. Hollander was responsive to student thinking, my focus redirection analysis does. I additionally found evidence that Mrs. Hollander has one delayed responsive focus redirection (F2) present in 2017-18, and not responsive focus redirections (F3) in 2014-15 (2 codes) and 2015-16 (1 code). These not responsive focus codes (F3) are slightly less frequent than the responsive focus codes (F1).

An example of a responsive focus redirection – terminology code is the following excerpt from 2016-17, when Mrs. Hollander is engaging in a whole class discussion around isotopes. Mrs. Hollander asks, "Okay, so let's have somebody else help me here, then, can someone tell me how you could describe an isotope to someone who has never taken chemistry? What might you say?" (Hollander 2016, 06:28). In this quote, Mrs. Hollander is asking the class to define the term isotope. Immediately prior to this question, Mrs. Hollander and her class are discussing radioactive decay, protons, neutrons, and isotopes. So, Mrs. Hollander is re-focusing her class on the idea of isotopes raised within the last verbal exchange.

When considering the results of my redirections analysis for Mrs. Hollander, my results suggest two things. First, over time, my results do not provide evidence for growth in Mrs. Hollander's responsiveness to student thinking. While there is evidence that Mrs. Hollander is responsive to her students' ideas (evidenced through focus responsive redirections, F1), these numbers do not increase over time and are low in count. Second, Mrs. Hollander employs a variety of activities in her classroom that support deep learning (A2; whole class and partner/small group discussion, and observation/investigation). While A2 codes are evidence for not responsive redirections, it is important to note that Mrs. Hollander uses strategies to engage students in science.

Mrs. Hollander: Teacher Professional Noticing v. Responsive Teaching

In order to consider how teacher professional noticing and responsive teaching compare, I want to consider only the genetics noticing task results to represent teacher professional noticing. The reason for this is because the video for genetics noticing task includes teacher-student interactions, while the sound noticing task is student-centric and does not include the teacher's voice. In considering only the genetics noticing task, I believe that I can make the best comparisons across the teacher professional noticing results and my redirections analysis.

For the genetics noticing task, one of the trends that I noted (Table 4.4) is the growth related to student thinking, represented by attention to and interpretation of CP. At the start of the PD program (2013), in response to the genetics noticing task, Mrs. Hollander discusses how students make sense of the phenomenon and engage in discussion. In 2016, Mrs. Hollander's responses increase in complexity to include not only making sense of the phenomenon and engaging in discourse, but using models to accomplish these tasks. Finally, at the end of the PD program, Mrs. Hollander explains that students in the video engage in discourse around the use, development, and revision models and explanations. These responses increase in complexity because Mrs. Hollander considers the context in which students engage in discourse around modeling. First, she does not acknowledge modeling, then she advances to using models, then further advances to revising models and explanations. When I consider this trend in comparison to my redirections analysis to account for responsive teaching, I recognize that Mrs. Hollander heavily engages her students in whole classroom discourse and small group discourse across all five years of classroom videos (Table 4.7). It seems that the not responsive activity redirections (A2) the Mrs. Hollander engages in in her classroom across all five years of the study, relate to what Mrs. Hollander pays attention to in the professional noticing task. It does not seem surprising that the primary activities that Mrs. Hollander engages in in her own classroom are aspects of instruction that Mrs. Hollander focuses on in response to the genetics professional noticing task.

Mrs. Hollander: Interview

During my interview with Mrs. Hollander, we watched and discussed her classroom video from the 2015-16 academic year. In this video, Mrs. Hollander leads a whole class discussion with her students around the strengths and weaknesses of atomic models that they have used in the class. In addition to whole class discussions, Mrs. Hollander sends her students into small groups throughout the class period to discuss atomic models to then return to the whole class discussion with ideas to share. Mrs. Hollander also presents her students with an atomic model that she created that addresses many of the weaknesses in the other models that the class noted, and asks her students how her own model could be improved.

The interview protocol asked Mrs. Hollander to pause the video at any moment that she found interesting or important. During the 37 minute and 52 second classroom video, Mrs. Hollander paused the video 21 times. The major theme I identified from Mrs. Hollander's interview is that she primarily evaluated her past teaching practices. Some aspects of Mrs. Hollander's teaching she evaluated were: whether she led her students too much or gave her students too much information, how partners were assigned, and how she supported students (EX: were her instructions or expectations clear?). Out of the 21 instances Mrs. Hollander chose to pause the video, 12 of those instances were to evaluate her teaching practices. The following quotation from our interview nicely depicts how Mrs. Hollander spent her time evaluating her teaching practices.

> "Well, I guess I can expand like… I'm thinking, am I letting them construct their knowledge? Or am I giving it to them? Right? Am I, am I actually letting them achieve that part of the performance expectation, where they're supposed to talk about limitations or am I being too obvious and not letting them actually discover it on their own?"

Mrs. Hollander both reflected and evaluated her teaching practices, using a lens of student thinking. She spent much of the time in our interview reflecting on whether her teaching practices in the video allowed her students to effectively learn the science content or if she was providing her students with too much information.

Another major theme I identified in this interview is discussion of whether students achieved the content goals of the lesson. Here, Mrs. Hollander reflected on whether student thinking was present in the video, the advantages or disadvantages of the atomic models, and creation of their own models. There were 6 instances in our interview that Mrs. Hollander reflected upon student thinking. The following quote from Mrs. Hollander reflects how she considered student thinking while watching her classroom video.

> "Well, I think that that some students are seeing the models and drawing like conclusions, maybe, right? Like some of them said that the yellow explosion looking stuff represents energy. Right? So, they were able to take the model and at least communicate what they thought some portion of it meant. And then the other student [spoke] about the idea of scale, right? Saying that the electrons should not be the same size as the proton… And so, they're able to like incorporate some stuff even from previous units right there."

Here, we see that Mrs. Hollander is considering student statements in the classroom video and considering how students are making sense of the models they are examining. These statements are the most reflective of teacher professional noticing and responsive teaching because Mrs. Hollander is taking up and considering the student ideas that are present.

Finally, there were 4 instances in which Mrs. Hollander chose to pause the video to explain what was occurring in the video but did not subsequently reflect on these moments in regards to specific student ideas.

> "I think it's going to give the students time to process and think about what we've already talked about. You know, like with advantages and disadvantages of the things we've kind of done together, but it's also going to let them incorporate some new stuff into it and own it a little bit more individually than just listening to me whole class."

In this final quote, Mrs. Hollander is explaining the purpose of sending her students out into small groups to discuss the advantages and disadvantages of models. Here, Mrs. Hollander is reiterating her goals for this instructional move but is not identifying student thinking or evaluating the instructional choice that she made. Additionally, I want to point out that while the total number of times that Mrs. Hollander chose to pause the video was 21 times, I have listed 22 instances here, this is because Mrs. Hollander both evaluated her teaching practices and reflected on student thinking during one of the moments she paused the video.

Summary of Results for Mrs. Hollander

My results do not provide evidence that Mrs. Hollander grew in her engagement across all three teacher professional noticing skills over the five-year PD program. Overall, I was able to identify growth in Mrs. Hollander's ability to attend and interpret. Additionally, my results provided evidence that Mrs. Hollander was minimally responsive to student thinking over the course of the five-year PD program. My redirections analysis allowed me to further characterize the types of activity shifts that occurred in Mrs. Hollander's classroom. These activities included: whole class discussion, individual students completing surface level tasks, small group or partner discussions, and observing or engaging in investigations. When considering my analysis of noticing and responsive teaching, I found a relationship between the not responsive activities that Mrs. Hollander engages in and what Mrs. Hollander talks about in response to the professional noticing task. Mrs. Hollander not only engages her students in large amounts of discourse across all five years of the PD program, she also increases in complexity in the ways in which she considers discourse in relation to the professional noticing task. Finally, in my interview with Mrs. Hollander, she focused primarily on evaluating her teaching practices, followed by noting how students were engaging with and learning the content being taught.

Mrs. Packer

Mrs. Packer teaches integrated science at a local middle school. She had 13 years of teaching experience at the start of the PD program in 2013, 18 years of experience by the end of the five-year PD program, and 19.5 years of total teaching experience by the time of my 2020 interviews. Mrs. Packer holds a bachelor's degree in marine biology and environmental studies, and a master's degree in education.

Mrs. Packer's Teacher Professional Noticing Trends

I selected Mrs. Packer to participate in my study because of the growth I noticed in both teacher professional noticing tasks for all three noticing skills. Namely, in the genetics noticing task (Table 4.8), I observed that Mrs. Packer increased in her attention to CP low level from 4 to 7 codes in 2013 to 2018, and interpretation for both CP (0 to 6 codes) and TMCF (1 to 7 codes). I want to note that Mrs. Packer increased in both categories of interpretation in the genetics noticing task from 2013 to 2018. This is important because engaging in the skill of interpretation is considered more challenging than engaging in the skill of attending (Jacobs et al., 2010). I observed that Mrs. Packer increased in noticing skills from 2013 to 2016 for attending CP (high level, 1 to 3 codes) and attending TMCF (high level, 1 to 2 codes). Growth was also found from 2016 to 2018 for attending TMCF (low level, 1 to 4 codes. I observed decreases in Mrs. Packer's teacher professional noticing from 2016 to 2018 in attending CP (high level, 3 to 1 codes) and attending TMCF (high level, 2 to 1 code).

Table 4.8: Genetics noticing task results for Mrs. Packer broken down by each major code category and year of sampling. Attending and interpretation are coded for.

Genetics Noticing Task (Video with Supplementary Work Samples)						
	At-CP High	At-CP Low	At-TMCF High	At-TMCF Low	Int-CP	Int-TMCF
2013	1	4	1	6	0	1
2016	3	3	2	1	4	5
2018	1	7	1	4	6	7

Below, I have included a portion of Mrs. Packer's responses to the genetics teacher professional noticing task (Figure 4.2). This prompt sought to elicit the participants to make interpretive statements about the genetics video that they were presented with. In 2016, Mrs. Packer is focused on the teacher and what the teacher is saying or doing to support the students. In contrast to this, in 2018, Mrs. Packer is focused on the students. Mrs. Packer addresses the science content and practices that the students engage with in the video. Mrs. Packer talks about problem-solving and explanations in 2018, where students are engaging in science as real scientists do. When thinking about the codes applied to these responses, the 2016 response was heavily coded for interpretative TMCF. In contrast to this, Mrs. Packer's 2018 response was more heavily coded for interpretative CP, focusing on the student ideas being presented in the task video.

Please describe in detail and provide your reaction to what the different students did to make sense of the anomalous (to them) data they found (be as specific as you can).	
2016	**2018**
The teacher acted as a guide encouraging the students and assuring them about the results. She pointed out that they couldn't use their current ideas to explain what they saw so they should see what they could change and what the new results could be. Acting as a reassuring guide gives the students room to explore.	As the students were analyzing the data they didn't just discard data they didn't fit their previous understanding. They seemed to consider it as a problem to be solved. They team reasoned that because there were more than 2 outcomes there had to be more than 2 allele types so they experimented with model with numbers to represent the alleles to try to come up with an explanation. My reaction/reflection of these student actions is that this is what we want to see students do when engaging in the SEP's really thinking and acting like "scientists."

Figure 4.2: Mrs. Packer's responses from 2016 and 2018 to a portion of the interpreting prompt of the genetics teacher professional noticing task.

For the sound noticing task (Table 4.9), again Mrs. Packer increases in her ability to interpret for CP from 10 to 23 codes in 2016 to 2018. However, Mrs. Packer also increases in her ability to respond to CP from 2016 to 2018 (2 to 4 codes). This is notable because these are considered higher-level skills that Mrs. Packer is engaging in. Mrs. Packer actually decreases in her attention to CP for both high (18 to 11 codes) and low level (10 to 6 codes) from 2016 to 2018. It is possible that because Mrs. Packer increases in her abilities to interpret and respond to CP, that Mrs. Packer then decreases in the amount of attention that is evidenced in her responses. Mrs. Packer also decreases in responding to TMCF from 2016 to 2018 (2 to 0 codes), and does not change in attention to TMCF (high level, 0 codes and low level, 1 code) and interpretation TMCF (2 codes).

Table 4.9: Sound noticing task results for Mrs. Packer broken down by each major code category and year of sampling. Attending, interpreting, and responding are coded for. Sampling occurred in 2016 (middle) and 2018 (final year of PD program).

Sound Noticing Task (Student Work Samples)								
	At-CP High	At-CP Low	At-TMCF High	At-TMCF Low	Int-CP	Int-TMCF	Resp-CP	Resp-TMCF
2016	18	10	0	1	10	2	2	2
2018	11	6	0	1	23	2	4	0

Similar to what I observed with Mrs. Hollander, my evidence does not provide evidence for growth across all three professional noticing skills consistently for Mrs. Packer. From the initial sampling to final sampling for each task, Mrs. Packer increased in some skills (genetics: At-CP low, Int-CP, and Int-TMCF; sound: Int-CP and Resp-CP), remained the same (genetics: At-CP High, At-TMCF high; sound: At-TMCF high and low, Int-TMCF), and decreased in other skills (genetics: At-TMCF low; sound: At-CP high and low, Resp-TMCF). Because I did not observe consistent growth, these results support the conclusion that it is challenging to develop teacher professional noticing skills (Jacobs et al., 2010). Mrs. Packer differs from Mrs. Hollander in that I observed growth across both tasks in relation to interpretation of CP, and responding to CP (only measured in the sound task). This is important to note because, ideally, I want to observe growth in these more advanced teacher professional noticing skills. Additionally, this growth is important because interpretation and responding to CP is related to student thinking, which is what the PD program sought to develop.

Mrs. Packer's Responsiveness to Student Thinking

Before diving into my redirections analysis (Tables 4.10 and 4.11), I am going to briefly describe Mrs. Packer's classroom videos over the course of the five year PD program. Mrs. Packer's first video submission in 2013-14 is focused on a dissection of owl pellets to understand what owls eat. Framing the investigation, Mrs. Packer leads her class in a whole class discussion on population dynamics related to owls. In the second year (2014-15), Mrs. Packer's students develop posters on green technology in order to sway their peers as to why their green technology is best. After creating their posters, the student groups present their posters to the class, and finally, the students vote on which green technology is best. In 2015-16, the third year of our PD program, Mrs. Packer leads her students through a whole class discussion reviewing survival of the fittest, and abiotic and biotic factors. The students then spend the rest of the class engaging in a small group card sort, working to determine which cards are biotic factors and which are abiotic factors. In the fourth year (2016-17), Mrs. Packer presents her class with a photo of a cougar that is well-hidden in the brush. She then leads her students through a whole class discussion about why this animal is suitable for the environment. In the primary activity students engage in a game where they simulate which offspring will survive and which offspring will not. Students work on their own and as a whole class to complete their datasheets and to make sense of the data they obtained during the simulation/game. In Mrs. Packer's final video submission (2017-18), students examine plate boundaries using maps. In this video, the class engages in primarily whole class discussion. Mrs. Packer sends her students to complete a worksheet individually and then discuss in their table groups what they reported.

Table 4.10: Activity redirections data table for Mrs. Packer's classroom videos across all five years of the PD program. Total number of codes for each activity redirection code are identified for each year. Cells without a code count are shaded in grey.

Code	2013-14	2014-15	2015-16	2016-17	2017-18
A1 - Responsive					
A2 – Whole class discussion	2	1	1	3	5
A2 – Individual develop/revise explanations/models					
A2 – Individual complete surface level work				1	3
A2 – Small group/partner discussion		2		1	2
A2 – Observation/investigation as whole class or groups	1		1	1	

For my analysis of Mrs. Packer's responsiveness to student thinking, I want to first focus on the activity redirection results, listed in the table above (Table 4.10). I did not find evidence that Mrs. Packer engaged in responsive activity redirections (A1) across all five years of the PD program. I found evidence that Mrs. Packer employs a variety of not responsive activity redirections (A2), reflective of the shifts in activities that her students engage in. It is important to note that these not responsive shifts in activities are likely reflective of pre-planned instructional decisions that Mrs. Packer made. I identified the types of activities Mrs. Packer has her students engage in in her classroom, these activities include: whole class discussion, individual student completion of surface levels tasks, small group or partner discussions, and engaging in observation or investigation.

An example where Mrs. Packer engages in a not responsive activity redirection (engaging in an investigation) can be found in her 2016-17 transcript. Leading up to this excerpt, the class is watching a video around characteristics that support survival of species. After the video ends, Mrs. Packer says, "And that's the question. Which one is going to be better at surviving? Okay, so here's the rules for your game. Thank you for asking, thank you for being really focused on what you need to be paying attention. So, for this, the rules will be up here," (Packer 2016-17, 22:51). Here, Mrs. Packer is shifting her students from watching a video on traits and survival to introducing an investigation and sending her students to engage in this investigation.

Mrs. Packer engages her students in observation or investigation during three out of the five years of the study (1 code in 2013-14, 2015-16, and 2016-17), as well as small group or partner discussion (2 codes in 2014-15 and 2017-18, and 1 code in 2016-17). Mrs. Packer engages her students in whole class discussion across all five years, this is the most engaged not-responsive activity redirection (2 codes in 2013-14, 1 code in 2014-15 and 2015-16, 3 codes in 2016-17, and 5 codes in 2017-18).

Table 4.11: Focus redirections data table for Mrs. Packer's classroom videos across all five years of the PD program. Total number of codes for each focus redirection code are identified for each year. Cells without a code count are shaded in grey.

Code	2013-14	2014-15	2015-16	2016-17	2017-18
F1 - TRM	1		4		2
F1 - REP					
F1 - MIN				1	
F1 - MOR					
F1 - CON					
F2 – Delayed responsive	2				
F3 – Not responsive					2

Unlike my analysis of activity redirections, Mrs. Packer demonstrates a responsiveness to student thinking as evidenced through focus redirections (Table 4.11). Similar to Mrs. Hollander, Mrs. Packer engages in only lower level focus redirections, these are F1-TRM (terminology) and F1-MIN (minimally responsive). Mrs. Packer varies in her engagement of F1-terminology redirections: 1 code in 2013-14, 4 codes in 2015-16, and 2 codes in 2017-18. Mrs. Packer only engages in F1-minimally responsive once in 2016-17. Evidence shows that Mrs. Packer also engages in delayed responsive redirections (F2) at the beginning of the PD program (2 codes in 2013-14) and in two not responsive focus redirections (F3) in 2017-18.

An example of a minimally responsive focus redirection (F1-MIN) occurs in 2016-17. Mrs. Packer's students have completed their survival of the fittest simulation and are working with Mrs. Packer to create a class data table. While students are sharing their results, Mrs. Packer asks the following question, "What are you guys noticing about this data? What is our population trending to in terms of…" (Packer 2016-17, 57:00). A student volunteers an answer before Mrs. Packer can finish her statement. I considered this a F1-MIN statement because students are presenting their results and Mrs. Packer shifts the focus to having students think about what the meaning of their results is. The focus shifts from a mere presentation of results to a consideration of what these results actually mean in terms of a community of species.

My evidence demonstrates that Mrs. Packer varies in her growth of responsiveness to students over the course of the five-year PD program. This growth in responsive focus redirections (F1) peaks in 2015-16 (4 codes) from 2013-14 (1 code), but then decreases in 2017-18 (2 codes). My evidence suggests that the most prevalent codes in Mrs. Packer's classroom videos are not responsive activity redirections (A2) accounting for a variety of classroom activities: whole class discussion, completion of surface levels tasks on-own, small group or partner discussions, and engaging in observation or investigation. Four of these not responsive activity codes support students' engagement with science and the activities support learning, however, they do not provide additional evidence that Mrs. Packer is responsive to the ideas that her students are raising in the classroom.

Mrs. Packer: Teacher Professional Noticing v. Responsive Teaching

When I draw comparisons between Mrs. Packer's responses on the genetics noticing task and my redirections analysis, I note a relationship between the not responsive activity redirections (Table 4.10) I identified in Mrs. Packer's classroom videos and her responses on the noticing task. In response to the genetics noticing task, Mrs. Packer increases in her ability to make interpretations about TMCF (Table 4.9). More specifically, over the five years of the PD program, Mrs. Packer's complexity in which she talks about the teacher's role in the classroom increases. At the start of the PD program, Mrs. Packer describes the teacher as filling the role of a facilitator. In 2016, Mrs. Packer discusses how the teacher in the genetics noticing task asks important probing questions, reflecting the role of a guide. Finally, in 2018, Mrs. Packer explains that in the task, the students make their own sense of the phenomenon, present their findings, while the teacher probes students along the way. These results align with some of my findings in the redirections analysis. First, in three out of five years of video, I found evidence that Mrs.

Packer engages in not responsive activity redirections for engaging in investigations (Table 4.10). When students engage in investigations in Mrs. Packer's classrooms, she visits the table groups asking questions that support or guide student thinking. This is much like the descriptions that Mrs. Packer highlights in relation to the professional noticing task. Second, Mrs. Packer engages in responsive focus redirections – terminology in three out of five years of the study. The questions that Mrs. Packer poses to the students in her classroom direct and guide the foci of discussion. This probing student thinking is reflective of the teacher viewed as a facilitator or guide that Mrs. Packer describes in the professional noticing task.

Mrs. Packer: Interview

Mrs. Packer and I watched her classroom video from the 2015-16 academic year. This video was 54 minutes in length. In this class period, Mrs. Packer begins by leading her students through a whole class discussion on biotic and abiotic factors. After the whole class discussion, Mrs. Packer sends the students out into small groups where they work on a card sort, making sense of different biotic and abiotic factors, and the patterns and relationships between the different factors.

During our 1 hour and 55 minutes-long interview, Mrs. Packer pauses the video 22 times to discuss interesting or important instructional moments she noticed in her classroom. Two themes emerged from my analysis of Mrs. Packer's interview: 1) why specific teaching decisions were made and 2) attention to content being taught or learned. 13 out of 22 instances that Mrs. Packer paused her classroom video accounted for Mrs. Packer explaining why she made particular instructional decisions. For example, Mrs. Packer discussed ideas such as probing student thinking to understand students' prior knowledge and providing students with opportunities to experience abiotic and biotic factors that will confront their current understandings. The following quote is an example from our interview in which Mrs. Packer discusses probing student thinking.

> "So, it has to do with probing for the student thinking and really trying to listen to where they're at and not just launching into the lesson or confirmation. Yeah, so I'm hearing students give responses that are both having to do with direct and indirect human impact on the environment and species. And so, you can hear me starting to probe them or trying to make those connections with these bigger ideas."

This quote shows how Mrs. Packer reflects on her decisions to probe student thinking and what the results of probing her students.

Next, I found that Mrs. Packer paused her classroom video 11 out of the 22 to consider content that was addressed in the lesson. Here, Mrs. Packer either identified the science content the students were being presented with or the extent students learned the science content being taught. For example, in the following quote, Mrs. Packer discusses how her students are making connections between different concepts, competition and organisms' or species' survival.

> "So, the student thinking is there, they're making connections to some of the concepts that we've learned about in terms of the organism survival versus the species survival and the differentiation between the organisms in the species. And they're also connecting back to prior units understanding of survival of the fittest… They're able to articulate some of those larger ideas and starting to apply it to our newer concepts of learning."

This quote shows how Mrs. Packer considers the science content being reviewed or taught in her classroom and how her students are applying this knowledge to newer ideas. Out of the 22 pauses, two instances are categorized for both instructional decisions and attention to science content. It is promising that Mrs. Packer has a large focus on student thinking while observing her classroom video. Additionally, it is important to note that while Mrs. Packer spent time reflecting on why she made particular instructional decisions, this was not reflective of redirections. Mrs. Packer did not identify moments in which she shifted activities or focus as important, rather she explained why she made particular instructional decisions in the context of supporting student learning.

Summary of Results for Mrs. Packer

Similar to Mrs. Hollander, I was unable to identify consistent growth across all three teacher professional noticing skills for both tasks. Instead, Mrs. Packer grew in her ability to interpret and respond to CP from the initial to final sampling for both tasks. My evidence also showed support of growth in Mrs. Packer's attention to CP (low level) in the genetics noticing task but not the sound noticing task. It is promising to see that Mrs. Packer increased in her engagement in interpretation and responding because these skills are more challenging to engage in (Jacobs et al., 2010). Through my redirections analysis, I identified that Mrs. Packer was responsive to student thinking as evidenced through focus redirections (F1), however, there was no evidence for consistent growth of responsiveness observed over the five-year PD program. Additionally, this analysis allowed me to identify the types of activities that Mrs. Packer has her students engage in. These not responsive activities included: whole class discussion, completion of surface levels tasks on-own, small group or partner discussions, and engaging in observation or investigation. When comparing my results from the teacher professional noticing task to my redirections results (responsive teaching), I found a relationship between what Mrs. Packer focused on in the noticing task to the redirections that she engaged in in her own teaching. Namely, I found that Mrs. Packer talked a lot about the role the teacher had in the genetics noticing task video, describing the teacher as a guide and the probes that the teacher posed to support student learning. My evidence shows Mrs. Packer engaged in not responsive redirections for engagement in investigations, where she visited table groups to probe student thinking. Mrs. Packer also engaged in responsive focus redirections – terminology, in which Mrs. Packer probed and guided her whole class' thinking, much like what Mrs. Packer described in her responses to the noticing task. Finally, through my interviews, I found that Mrs. Packer spent about equal time identifying why she made instructional decisions and identifying science content that was being engaged in. The latter is important because this is reflective of a teacher professional noticing or responsive teaching lens, in that there is attention on what the students are learning and thinking in the classroom.

Mr. Sanchez

Mr. Sanchez is the most experienced teacher in my study. Mr. Sanchez had 18 years of teaching experience at the start of the PD program in 2013, 23 years by the end of the PD program, and 24.5 years of teaching experience by the time I interviewed him in 2020. Mr. Sanchez holds a bachelor's degree in biology and a master's degree in education. Mr. Sanchez teaches middle school life science.

Mr. Sanchez's Teacher Professional Noticing trends

I selected Mr. Sanchez to participate in the present study due to my observation of growth in relation to content and interpretation CP codes from the initial to final samplings for both the genetics and sound noticing tasks. Moreover, I selected Mr. Sanchez because interpretation of student thinking (CP), is considered a higher-level skill for teacher professional noticing. In trying to determine if growth in teacher professional noticing leads to growth in responsive teaching, I believed that selecting Mr. Sanchez would increase the likelihood of this observation because I observed growth in the higher level noticing skill of interpretation.

In the genetics noticing task (Table 4.12), I observed growth in two areas from 2013 to 2018, these are for attending CP high level (0 to 3 codes) and interpretation CP (0 to 9 codes). These increases in attention and interpretation to student thinking were ideal because they reflect a student-centered focus, which is what we sought to support development of in the PD program. I also found that Mr. Sanchez increased in attending TMCF (low level, 6 to 7 codes) in 2013 to 2016, and increased in attending CP (low level, 2 to 5 codes) in 2016 to 2018. I also noted decreases in code counts for the genetics professional noticing task. Mr. Sanchez decreased in interpretation TMCF from 2013 to 2018 (3 to 1 codes), attending CP (low level, 5 to 2 codes) from 2013 to 2016, and attending TMCF (low level, 4 to 4 codes) in 2016 to 2018. These decreases in codes could be a result of Mrs. Sanchez engaging more in attending and interpreting CP or as result of the growth ceiling, reached at two years of PD engagement, described by Jacobs and colleagues (2010).

Table 4.12: Genetics noticing task results for Mr. Sanchez broken down by each major code category and year of sampling. Attending and interpretation are coded for.

Genetics Noticing Task (Video with Supplementary Work Samples)						
	At-CP High	At-CP Low	At-TMCF High	At-TMCF Low	Int-CP	Int-TMCF
2013	0	5	1	6	0	3
2016	3	2	1	7	2	2
2018	3	5	1	4	9	1

Below are excerpts from Mr. Sanchez's responses to the genetics noticing task, sought to elicit the attending skill (Figure 4.3). One of the most notable differences from Mr. Sanchez's responses in 2013 and 2018 is that Mr. Sanchez primarily attends to low level TMCF in 2013 and attends to high level CP in 2018. These excerpts provide evidence for the growth in attending for Mr. Sanchez from the start to the end of the PD program. In 2013, Mr. Sanchez describes three important aspects of the classroom that support student thinking. Whereas in 2018, Mr. Sanchez has a larger focus describing what the students are doing. Attention to student thinking (CP) is much more desirable than attention to teacher or classroom centered aspects of instruction (TMCF).

Everyone views instructional situations differently. What 3 aspects of this video did you find noteworthy?	
2013	**2018**
1) Collaborative groups of 3 – students talking to each other and working out problems. … 2) Teacher posing questions – teacher gave enough information and asking questions to help "lead" students to solutions, but did not give the solutions. … 3) Use of technology – provided quick, easily manipulated data for students to use and thinking about. Students were using information instead of searching for information. …	1) Students are asked to make a model and make sense of a phenomenon (computer simulation). 2) Students were given a task that built on their prior understanding and models (i.e. "two alleles for every trait" was challenged). … 3) Students were using and analyzing data, thinking about systems, and changing components of a system to see cause and effect, and constructing explanations based on their evidence and observations.

Figure 4.3: Mr. Sanchez's responses from 2013 and 2018 to a portion of the attending prompt of the genetics teacher professional noticing task.

For the sound noticing task (Table 4.13), I noted growth in three areas; attention to CP low level (7 to 10 codes), attention to TMCF (0 to 2 codes), and interpretation of CP (13 to 19 codes). There was a relatively low count of TMCF codes for attending (TMCF high, 0 codes; TMCF low, 0 to 2 codes), interpreting (3 codes), and responding (1 code) for the sound noticing task. Additionally, I found decreases in attending CP (high level, 12 to 11 codes) and responding CP (3 to 2 codes). While I may not see consistent increases across all three teacher professional noticing skills, it is promising to see that Mr. Sanchez appears to focus more on student ideas than other instructional characteristics (TMCF) that are present in the sound noticing task.

Table 4.13: Sound noticing task results for Mr. Sanchez broken down by each major code category and year of sampling. Attending, interpreting, and responding are coded for. Sampling occurred in 2016 (middle) and 2018 (final year of PD program).

Sound Noticing Task (Student Work Samples)								
	At-CP High	At-CP Low	At-TMCF High	At-TMCF Low	Int-CP	Int-TMCF	Resp-CP	Resp-TMCF
2016	12	7	0	0	13	3	3	1
2018	11	10	0	2	19	3	2	1

Similar to both Mrs. Hollander and Mrs. Packer, I did not find evidence for growth consistently across all three teacher professional noticing skills for Mr. Sanchez. While each participant grew in different ways in relation to teacher professional noticing, there are some similarities. Both Mrs. Packer and Mr. Sanchez increased in their interpretation of CP for both teacher professional noticing tasks. And Mrs. Hollander and Mr. Sanchez grew in their attention to CP across both noticing tasks. While neither Mrs. Hollander and Mr. Sanchez grew in their ability to respond over the PD program. These results show that different individuals learn how to engage in teacher professional noticing skills in different trajectories, despite engaging in the same five-year long PD program.

Mr. Sanchez's Responsiveness to Student Thinking

In the following section, I will briefly describe each of Mr. Sanchez's videos that I analyzed for the redirection analysis, I will then present my redirections analysis for these videos. In Mr. Sanchez's first video (2013-14), Mr. Sanchez and his students focus on skeletal muscle fatigue. He leads his students through multiple whole class discussions, broken up by students completing a set of questions on a worksheet and talking about these questions in student groups. In 2014-15, Mr. Sanchez and his students explore the nutritional value of foods. The class format varies between whole class discussions and table group discussions to determine the nutritional values of foods like pizza. In this video, students are expected to develop an explanation with evidence and reasoning about the nutritional value of a self-selected food. Mr. Sanchez's third video submission (2015-16) focuses on the advantages and disadvantages of sports drinks and energy drinks. Students use a scientific article to collect evidence about these drinks to develop their claims regarding sports drinks. Students engage in discussions and individual sensemaking in order in order to develop a claim with supporting evidence and reasoning. In 2016-17, Mr. Sanchez's class discusses and explores reflexes and muscle memory. The class watches a video of a baseball player hitting a ball with a bat. They engage in both whole class and small group discussions to make sense of whether professional baseball players hitting a ball is a reflex or muscle memory. Students were expected to develop an explanation for what occurs between the brain and the muscles in order for this phenomenon to happen. In Mr. Sanchez's final video (2017-18), the class focuses on the rainforest as an ecosystem and why it is so important. Students engage in internet searches to find evidence for the importance of rainforests. Mr. Sanchez engages in a read aloud with his students, providing the class with another source of information. Students spend time in small groups and as a whole class discussing why rainforests are such a critical ecosystem.

Table 4.14: Activity redirections data table for Mr. Sanchez's classroom videos across all five years of the PD program. Total number of codes for each activity redirection code are identified for each year. Cells without a code count are shaded in grey.

Code	2013-14	2014-15	2015-16	2016-17	2017-18
A1 - Responsive			1		
A2 – Whole class discussion	3	3	1	3	4
A2 – Individual develop/revise explanations/models		1	1	2	
A2 – Individual complete surface level work	2		1	1	2
A2 – Small group/partner discussion	2	2	1	3	2
A2 – Observation/investigation as whole class or groups			3	1	3

Mr. Sanchez is the only participant in my study that was identified to use a responsive activity redirection (A1), this occurred during year three of the five-year PD program (1 code in 2015-16) (Table 4.14). Second, my evidence showed Mr. Sanchez had the highest number of not responsive activity redirections (A2) out of the three participants. Mr. Sanchez has evidence of engaging in all five not responsive activity redirections, almost consistently through all five years of the study. Two of these activity redirections were the most identified (highest number of codes) and were present across all five years – whole class discussion (3 codes in 2013-14, 2014-15, 2016-17; 4 codes in 2017-18; and 1 code in 2015-16) and small groups or partner discussion (2 codes in 2013-14, 2014-15, 2017-18; 3 codes in 2016-17; and 1 code in 2015-16). I found evidence that two not responsive activity redirections were present in three out of the five years –

individual students develop explanations or revise models (1 code in 2014-15 and 2015-16, and 2 codes in 2016-17) and engaging in observation or investigation (3 codes in 2015-16 and 2017-18, and 1 code in 2016-17).

The only responsive activity redirection found in my dataset was present in Mr. Sanchez's 2015-16 classroom video. Mr. Sanchez begins this class with a warm-up where students share their food logs from the previous day and engage in a whole-class discussion about the nutritional value of these foods. The class moves onto reading an article about energy drinks and their nutritional value as a whole-class. After completing the article, Mr. Sanchez has his students list the advantages and disadvantages of energy drinks on individual white boards. Mr. Sanchez asks his students to share their boards and reads the different responses aloud.

> "Let me get a gauge of what we're thinking here. [Mr. Sanchez reads the boards aloud] What's funny is, anyone notice that on the advantage, we said all full of carbohydrates, which is sugar. But then on the disadvantage, a lot of you said disadvantage is they are full of sugar. So, what's the difference between? Is there any reason why we think it's kind of good in one way, then it's kind of bad in the other way? Let's listen," (2015-16 Sanchez, 39:36).

I considered the quote above a responsive activity redirection because Mr. Sanchez attempts to shift the students' activity from sharing out the pros and cons of energy drinks to making sense of why sugar, a carbohydrate can be both beneficial and harmful. Additionally, this is responsive because Mr. Sanchez is using the student ideas shared on the white boards to further probe their ideas and understandings about carbohydrates. Because carbohydrates/sugar is an idea raised by the students, this is considered responsive.

An example in which Mr. Sanchez engages in a not responsive activity redirection for developing explanation can be found in his second classroom video (2014-15). At the beginning of this video, the students are given a warm-up task to record a recent food they had eaten and its nutritional value. In this particular talk sequence, Mr. Sanchez and his students are discussing different fatty foods as a whole class. A student raises the idea of peanut butter as a fatty food. After discussing this as a class, Mr. Sanchez says, "I want to give you guys a chance to revise and edit your conclusions. We had a question that said, why does the heart rate increase during exercise. What do the other systems themselves need to explain why. Be specific," (Sanchez 2014-15, 08:06). In this excerpt, Mr. Sanchez is shifting the activity that the students are engaged in from a discussion of the nutritional value of foods to revising explanations about heart rate. This shift was not responsive to any student statement, rather an instructional decision made by Mr. Sanchez that was unrelated to the current talk sequence at hand.

The final not responsive activity redirection I found evidence for in the dataset for was individual completion of a surface level task. Mr. Sanchez also almost consistently has his students are engaging in completion surface level tasks, this code was identified in four years of the study (1 to 2 codes per year). With the exception of surface level task completion, I would consider the other A2 codes to be preferable, though not responsive to student thinking, because they support student engagement in science.

Table 4.15: Focus redirections data table for Mr. Sanchez's classroom videos across all five years of the PD program. Total number of codes for each focus redirection code are identified for each year. Cells without a code count are shaded in grey.

Code	**2013-14**	**2014-15**	**2015-16**	**2016-17**	**2017-18**
F1 - TRM	1			3	
F1 - REP					
F1 - MIN					
F1 - MOR					
F1 - CON					
F2 – Delayed responsive			2	1	
F3 – Not responsive	1			1	

Through my focus redirections analysis (Table 4.15), I found that Mr. Sanchez engaged in only one type of responsive focus redirection – F1-TRM (terminology). Mr. Sanchez grew in his engagement of this focus redirection from 1 instance in 2013-14 to 3 instances of F1-TRM in

2016-17. No other responsive focus redirection (F1) codes were identified in Mr. Sanchez's classroom videos. Similar to both prior participants, I found evidence that Mr. Sanchez engaged in delayed responsive focus redirections (F2) in 2015-16 and 2016-17, and not responsive focus redirections (F3) in 2013-14 and 2016-17.

An example of an excerpt in which a delayed responsive focus redirection code was applied can be found in Mr. Sanchez's classroom video from 2015-16. In this video, students are considering the advantages and disadvantages of sports drinks and energy drinks. While reading an article aloud to the class about these drinks, Mr. Sanchez says the following, "Here's a connection to our heart rate lab. Why do you think food will not be digested very well if you are currently exercising or running or moving? Think about to last week we talked about this. […] Why would it be better to drink something?" (Sanchez 2015-16, 20:17). In this excerpt, Mr. Sanchez is having his students shift from a focus on energy drinks to a previous activity on heart rate. This would be considered a delayed responsive focus redirection because Mr. Sanchez revisits a phenomenon from the prior week.

In consideration of the redirection analysis, Mr. Sanchez did slightly increase in his responsiveness to student thinking. He grew from zero responsive activity redirections (A1) in 2013-14 to one code in 2015-16. He additionally grew in his responsive focus redirections (F1) from one code in 2013-14 to three codes in 2016-17. Out of the three teachers, Mr. Sanchez was the only participant to have a responsive activity redirection (A1), however Mr. Sanchez had fewer responsive focus redirections (F1) than the other participants. Mr. Sanchez has a total of 4 F1 codes, while Mrs. Hollander has 5 F1 codes, and Mrs. Packer has 8 F1 codes. When taking this into consideration, it appears that Mr. Sanchez and Mrs. Hollander are equally responsive to student thinking, while Mrs. Packer has a slightly higher responsiveness to student thinking.

Finally, my redirections analysis allowed be to identify the types of not responsive activities that Mr. Sanchez engages his class in, where he had the largest variety out of the three participants, engaging in all five activities that were coded for in this dataset.

Mr. Sanchez: Teacher Professional Noticing v. Responsive Teaching

Mr. Sanchez is the only teacher in my study to have evidence of engaging in the not responsive activity redirection - students developing and revising models (Table 4.14). This is notable on its own but it also allows me to draw comparisons across the genetics noticing task and my responsive teaching analysis using redirections. In response to the genetics noticing task, Mr. Sanchez develops in the ways in which he talks about models (Figure 4.3). In 2013, Mr. Sanchez talks about the technology or simulation that the students use, while not acknowledging that this is a model. In 2016, Mr. Sanchez recognizes that the simulation is a model that the students are using. While in 2018, Mr. Sanchez explains that students develop models to understand the phenomenon. In the beginning of the PD program, my evidence suggests that Mr. Sanchez does not acknowledge the different types of models students can manipulate, whereas by the end of the PD program, Mr. Sanchez recognizes that students can take ownership over creating meaningful models. Mr. Sanchez's increased complexity in which he talks about models seems to run parallel to his increased redirections of modeling (Table 4.14). Mr. Sanchez has no modeling redirections in 2013-14, increases to 1 code in 2014-15 and 2015-16, then 2 codes in 2016-17. This increased attention to modeling in the genetics professional noticing task seems to be related to Mr. Sanchez's engagement in modeling redirections in his own teaching.

Mr. Sanchez: Interview

Mr. Sanchez and I watched his 2016-17 classroom video. This video was 44 minutes and 51 seconds in length. This video has a content focus of the nervous system. Students begin by completing a warm-up individually, followed by the students exchanging their work to discuss what should be added or revised to their work. Mr. Sanchez leads his students through a whole class discussion of the nervous system and reflexes before sending his students to, again, share their ideas with peers. He also provides the students with a video of a baseball player hitting a ball with the bat, in which students develop models and then discuss their ideas in both whole-class and partner settings.

During Mr. Sanchez's one hour and 57 minutes interview, Mr. Sanchez pauses the video 17 times to discuss the instructional moments that he found interesting or important. I found that Mr. Sanchez had all three interview themes present: 1) evaluation of teaching practices, 2) why specific teaching decisions were made, and 3) attention to content taught/learned. There were two instances where Mr. Sanchez evaluated his teaching practices. In these instances, Mr. Sanchez considered whether his practices were effective (EX: are the directions clear? Can I evaluate student thinking from this?). For example, in the following quote, Mr. Sanchez reflects on his choice of having his students write a summary of their homework versus a more structured prompt.

> "I should have had more specific directions. … Like what question do you have or what is something you're confused about or what is something you really feel strongly about? Giving them more options as opposed to a summary. Because summaries are challenging for, I think, middle school students, seventh graders. Because they don't always know what to write and they can give varied answers and that doesn't really give you any good information about what they understood about what they're trying to summarize."

In this quote, we see that Mr. Sanchez is reflecting back on the type of prompts he gave his students and explaining that the prompt might lead to students struggling on what to write and not providing the teacher with sufficient information on what his students know.

Mr. Sanchez also spent time in our interview explaining why he made particular teaching decisions, there were five instances of this. In these instances, Mr. Sanchez elaborates why he chose to paraphrase a student's idea or why he selected a particular student to explain their thinking to the whole-class. In the following quote, Mr. Sanchez explains his reasoning for paraphrasing a student's idea in the whole-class discussion.

> "I'm trying here to paraphrase or restate what he's saying. I'm not trying to add any more information. I may be expanding a little bit on what he said, but I don't think I'm trying to give information. I'm trying to get him to confirm in that moment because I'm trying to explain it again. I'm trying to restate it so the whole class hears that [idea]."

In this portion of the interview, Mr. Sanchez explains why he chose to reiterate a student's idea, which was to highlight this idea and to make sure that the other students heard this point because it is important.

Finally, I found Mr. Sanchez also paid attention to the student ideas and content that was being addressed in the video. There were nine out of the 17 instances where Mr. Sanchez focuses on the science content. In these instances, Mr. Sanchez talks about the science that the students are learning and the models that the students are drawing. The following quote exemplifies how Mr. Sanchez obtains and evaluates the student thinking in his classroom.

> "Okay, so that student I'm asking how does that article relate to that initial phenomenon or model. I'm trying to have them draw [a model of the baseball player] and that student says electrical signals which is good because again there's a flow of information or there's you know inputs and outputs. So, there's signals being sent out of the brain."

In this quote, we see that Mr. Sanchez elicits student thinking and evaluates the student's understanding of science content. These statements are particularly important because they are focused on student thinking and student understanding of the content being taught. The more prevalent instances of Mr. Sanchez discussing instructional decisions and student ideas is reflective of teacher professional noticing and responsive teaching because they take on a lens that is focused on supporting student learning through student-focused instruction and analyzing how students are learning in the classroom. Additionally, it should be noted that 16 pauses are accounted for in the prior discussion, the last pause was not relevant to my analysis, where Mr. Sanchez asked a logistical question.

Summary of Results for Mr. Sanchez

Across both teacher professional noticing tasks, I found that my evidence showed inconsistent growth for Mr. Sanchez across all three teacher professional noticing skills. I found that Mr. Sanchez grew in his interpretation of CP across both tasks, and his attending to CP (high level in genetics and low level in sound). This is why I selected Mr. Sanchez to participate in the present study because I was seeking a participant who I had observed growth in relation to student thinking. Mr. Sanchez was the only participant who had a responsive activity redirection (A1). However, when considering all responsive redirection codes, Mr. Sanchez and Mrs. Hollander were equally responsive. Mr. Sanchez, like the other two participants, had evidence of many more not responsive codes than responsive codes, which suggests that the participants in my student were minimally responsive to student thinking in their classrooms. When I consider the results for professional noticing and responsive teaching, I found a relationship in regards to modeling. Mr. Sanchez increased in the complexity in which he talked about modeling in the genetics noticing task. Mr. Sanchez was also the only participant who had evidence of engaging in the not responsive redirection for students engaging in modeling. It seems that Mr. Sanchez's growth in thinking about modeling and his engagement in this activity may correspond. Finally, in my interview with Mr. Sanchez, I found that he spent most of the interview reflecting in a student-centered manner. Mr. Sanchez spent time explaining why he made particular instructional decisions to support student learning and time elaborating on the science ideas that students were raising in his classroom.

Cross-case Analysis: Teacher Professional Noticing

The tables below (Tables 4.16 and 4.17) depict the results for each professional noticing task, for all three participants as a whole. For both tasks, I did not find evidence of consistent growth in attending, interpreting, and responding from the initial to final timepoints. As a reminder, the genetics noticing task accounted for attending and interpreting. When considering the whole dataset for the genetics noticing task, I identified growth in: attending CP (high and low levels), attending TMCF (high level), and both interpreting CP and TMCF (Table 4.16). For the genetics task, there were three timepoints and growth was not observed to increase across these five years. First, I determined that there was growth from 2013 to 2016 (initial to mid-point) for attending CP (high) (1 to 8 codes) and attending TMCF (high) (3 to 7 codes). There was no growth in these categories from 2016 to 2018. Next, I determined there was consistent growth from 2013 to 2018 (initial to final timepoints) for both interpretation categories, CP (0 to 7 to 21) and TMCF (6 to 9 to 10). Finally, there was growth from 2016 to 2018 for attending TMCF (low level, 10 to 12 codes). I also observed decreases in my overall genetics' dataset. From 2013 to 2016 there were decreases in attending CP (low level, 12 to 10) and attending TMCF (low level, 18 to 10). I also noticed a decline from 2016 to 2018 for attending TMCF (high level, 7 to 3).

Table 4.16: Genetics noticing task results for all three participants, broken down by each major code category and year of sampling. Attending and interpreting are coded for. Sampling occurred in 2013 (start), 2016 (middle), and 2018 (final year of PD program).

Genetics Noticing Task (Video with Supplementary Work Samples)						
	At-CP High	At-CP Low	At-TMCF High	At-TMCF Low	Int-CP	Int-TMCF
2013	1	12	3	18	0	6
2016	8	10	7	10	7	9
2018	8	17	3	12	21	10

The sound noticing task was administered in 2016 and 2018, marking the midpoint and endpoint for the PD program. The sound noticing task analysis accounted for all three professional noticing skills. I observed both increases and decreases from 2016 to 2016 (Table 4.17). I found increases in attending CP (high level, 45 to 49 codes), attending TMCF (low level, 4 to 7), interpretation CP (29 to 48), and interpretation TMCF (5 to 8). I saw decreases in the total number of codes from 2016 to 2018 in attending CP (low level, 36 to 31), responding CP (10 to 8), and responding TMCF (8 to 6).

Table 4.17: Sound noticing task results for all three participants, broken down by each major code category and year of sampling. Attending, interpreting, and responding are coded for. Sampling occurred in 2016 (middle) and 2018 (final year of PD program).

Sound Noticing Task (Student Work Samples)								
	At-CP High	At-CP Low	At-TMCF High	At-TMCF Low	Int-CP	Int-TMCF	Resp-CP	Resp-TMCF
2016	45	36	0	4	29	5	10	8
2018	49	31	0	7	48	8	8	6

When considering the analyses of both professional noticing tasks, I note some similarities in growth trends. Across both tasks, I found growth in attending to CP (high level), and growth in interpreting CP and TMCF. I did not find evidence of growth across both tasks in attending to CP (low level) and attending to TMCF (high and low levels). These results are promising for two reasons; 1) growth in attention to high level student thinking (CP) is more desirable than attention to all other things (TMCF), and 2) growth in a more challenging professional noticing skills (in this case interpretation) shows teachers are able to develop these higher-level skills over time with PD.

Cross-case Analysis: Redirections

Below are the results of my redirection coding analysis (Table 4.18). This table includes the total number of codes applied to my full data set. These are totals for all five videos for each of the three participants. I am showing this summary table for three reasons: 1) to demonstrate how many more activity codes were applied to the dataset than focus codes, 2) to demonstrate the need for classifying the not responsive activity redirections (A2), and 3) to show that when teachers engaged in responsive focus directions, they were strictly low level (F1-TRM and F1-MIN).

Table 4.18: Total number of redirections codes per code type. Total includes the number of codes applied for all three participants, across all five years of classroom video analyzed.

Name of Code	Total Number of Codes Applied
A1 (Responsive)	1
A2 – Whole class discussion	44
A2 – Individuals develop/revise explanations/models	4
A2 – Individuals complete surface level tasks	11
A2 – Small group/partner discussion	27
A2 – Observation/investigation as whole class or in groups	16
F1 - TRM	14
F1 - REP	0
F1 - MIN	3
F1 - MOR	0
F1 - CON	0
F2 (Delayed Responsive)	6
F3 (Not Responsive)	7

Between all 15 transcripts I analyzed, I identified a total of 103 activity redirections and 30 focus redirections. Initially, I used Lineback's (2014) redirections coding scheme verbatim. As a result of this, I identified 102 not responsive activity redirections (A2) in my data set. These A2 codes all represented shifts in the activities that were occurring in the participants' classrooms that were preplanned and not responsive to students' ideas. Due to this pattern and my notes on the distinct differences between activities observed in the classrooms, I felt that it was necessary to classify the different activities being observed. Upon this analysis, I identified five different non-responsive activity redirections: 1) whole class discussion, 2) individual students developing or revising their explanations or models, 3) individual students completing surface level tasks, 4) small groups or partner discussions, and 5) conducting observations or investigations as a whole class or in groups. While the total number of focus redirections were small, there are obvious trends apparent across the dataset. Namely, I saw only two types of responsive focus redirections (F1) present in the data, teachers requesting students to identify or explain a term (F1-TRM) and redirections that were minimally related to student comments (F1-MIN). It is important to acknowledge that these responsive focus redirections were the only F1 codes identified in my dataset because they are considered to be lower level than the F1 codes: F1-MOR and F1-CON, which request students to extend or elaborate students' ideas and request students to consider students' ideas (Lineback, 2014).

Overall, my results from the redirections analysis show me that, when considering the results for all five years of my study, teachers were minimally responsive to student thinking. This is evidenced by the low number of F1 and A1 codes. Additionally, the large number of not responsive codes (A2 and F3) and delayed responsive codes (F2) show that teachers respond to ideas or activities unrelated to student thinking.

Cross-case Analysis: Interviews

As a reminder, the major themes that I identified in each of my participants' interviews were: 1) evaluation of teaching practices, 2) why specific teaching decisions were made, and 3) attention to content taught/learned. Mrs. Hollander primarily evaluated her teaching practices while observing her classroom video. Mrs. Packer split her attention between explaining why she made particular instructional decisions and identifying the student ideas and science content being taught. Mr. Sanchez's interview transcript accounted for all three major themes, however, he spent minimal time evaluating his teaching practices and spent the majority of his time considering the student thinking present in his classroom video. Mrs. Packer and Mr. Sanchez's interviews are most reflective of teacher professional noticing and responsive teaching. This is because of their focus on student thinking and supporting student learning through specific instructional decisions. Additionally, I did not find that any of my three participants identified shifts in focus or activity as important moments of instruction (redirections). This suggests that analyzing responsiveness through redirections is more reflective of a researcher-lens than that of the participant.

Conclusion

In Chapter 5, I will discuss how the findings above address my research questions. Because this study is a three-person case study, it is important to acknowledge that this is a limitation for making overarching conclusions regarding teacher professional noticing and responsive teaching. In contrast, my longitudinal study provides supporting evidence for these two frameworks and allows me to begin drawing some comparisons between teacher professional noticing and responsive teaching. The research questions that drove my study are as follows:

1) In what ways does teachers' responsiveness to student thinking shift during an extended professional development program with a focus on students' scientific thinking?
2) In what ways do teachers grow in relation to their professional noticing skills and their responsiveness to student thinking, during the course of a five-year professional development program focused on student thinking?
3) During instruction, what instructional moments do teachers identify as critical moments, and how do these moments relate to teachers' responsiveness to student thinking?

Chapter 5: Discussion, Limitations, Future Redirections

Discussion

Introduction

It is proposed that teacher professional noticing is a precursor to responsive teaching (Richards and Robertson, 2016). Until the present study, there has been no attempt published to provide empirical evidence that supports the relationship between teacher professional noticing and responsive teaching. In order to understand the relationship between these frameworks, I conducted a longitudinal analysis of data using research methods from the lenses of both professional noticing and responsive teaching. I proposed the following research questions to examine teacher professional noticing and responsive teaching:

1) In what ways does teachers' responsiveness to student thinking shift during an extended professional development program with a focus on students' scientific thinking?
2) In what ways do teachers grow in relation to their professional noticing skills and their responsiveness to student thinking, during the course of a five-year professional development program focused on student thinking?
3) During instruction, what instructional moments do teachers identify as critical moments, and how do these moments relate to teachers' responsiveness to student thinking?

Summary of the Results

The present study examines three experienced secondary science teachers who participated in an extended five-year PD program with an emphasis on teacher professional noticing and student thinking. Through an analysis of two teacher professional noticing tasks, I identified the three participants to invite to participate in my study. The purpose of using the professional noticing task results to determine which participants to invite was to identify three participants who had grown in their ability to attend, interpret, and/or respond to student thinking over the course of the PD program. The thought behind this is that if I select participants who grew in their noticing skills, I may also observe growth in their responsiveness to student thinking, if the proposition by Richards and Robertson (2016) is true, and noticing is a precursor to responsiveness.

I found that the participants in my study developed in relation to the different teacher professional noticing skills in different ways. Mrs. Hollander increased in her attention to CP for both tasks. In contrast, Mrs. Hollander increased in her interpretation of CP in response to the genetics task but did not change in this measure in response to the sound task. My evidence does not show that Mrs. Hollander increased in the skill of responding. Across both tasks, Mrs. Packer increased in her ability to interpret CP. Mrs. Packer's attention to CP increased for both tasks, however, they were high level CP codes for the sound task and low level CP codes for the genetics task. She increased in her responding CP skill for the sound task, as well. Finally, Mr. Sanchez grew in his abilities to attend and interpret CP across both noticing tasks. My evidence does not show growth in the responding skill for Mr. Sanchez. Similar results were reported in at least three other studies, which concluded that teachers who participate in the same PD programs or courses will have different trajectories for development of their teacher professional noticing skills (Amador et al., 2017; van Es et al., 2017; van Es and Sherin, 2008). Jacobs and colleagues (2010) report the challenges of developing teacher professional noticing skills, as well as Amador et al. (2016) who report that interpretation is less-frequently engaged in than attending.

To examine teachers' responsiveness to student thinking over the course of a five-year PD program, I examined these same teachers' classroom videos. Each teacher submitted one classroom video for each year they participated in the PD program, and were asked to submit videos that represented their everyday teaching practices. In order to conduct my analysis, I adapted Lineback's (2014) redirections coding scheme. My adaptation to this coding scheme included further categorization of not responsive activity redirections. These codes are: 1) whole class discussion, 2) individual students developing or revising their explanations or models, 3) individual students completing surface level tasks, 4) small groups or partner discussions, and 5) conducting observations or investigations as a whole class or in groups. These codes reflect the important instructional decisions that these teachers made to support their students' engagement in science, while not being responsive to the student ideas being presented during instruction.

Through my analysis, I found that the three teachers in my study were minimally responsive to student thinking, this was evidenced by few responsive activity and focus redirections. There was a much higher prevalence of not responsive codes present in my results, especially in regards to not responsive activity redirections. I found that Mrs. Hollander engaged in whole class and small group discussion redirections across all five years of the dataset, and observation or investigation redirections three out of the five years. Mrs. Packer also engaged in the whole class discussion redirection for all five years. She also engaged in small group discussion and observation and investigation redirections three out of the five years. Mr. Sanchez engaged in all five of the activity redirections that I accounted for in my analysis, and was the only teacher to engage in the redirection - developing/revising explanations/models. The affordances that Lineback (2014) describes in her creation and analysis of redirections are true for my analysis as well. I was able to employ redirections to analyze the instructional practices teachers engaged in, observe individuals over time, and to compare responsiveness across cases (Lineback, 2014). My results, however, do not appear to support prior findings that PD focused on student thinking support teachers' responsiveness to student thinking (Levin et al., 2009; Lineback, 2014).

Finally, through my interview analysis, I was able to identify three major categories in which teachers focus their attention on when reflecting upon their own classroom videos. These categories are: 1) evaluation of teaching practices, 2) explanation of why specific teaching decisions were made, and 3) attention to content taught/learned. All three of the teachers in my study gave attention to the science ideas that students raised in their classrooms, this was most often done by talking about the science content that the students had learned or the extent in which students had demonstrated understanding this content. This result that teachers are responsive to student thinking while examining classroom teaching is consistent with prior findings (Dyer and Sherin, 2015). Mrs. Hollander and Mr. Sanchez engaged in evaluation of their teaching practices, considering whether particular strategies would support student learning or would allow student ideas to be assessed. Mrs. Packer and Mr. Sanchez engaged in explaining why particular teaching decisions were made. They often explained why they pursued particular student ideas or decided to sequence their instructional activities in a particular way. Attention to details of instruction or the evaluation of instructional techniques was previously reported (Dyer and Sherin, 2015; Johnson et al., 2017).

Above, I have summarized the overall results of my study. I have also considered how the results of my noticing and responsive teaching analyses compare to findings currently reported in the literature. The following sections are broken down by each of my three research questions. For each question, I will present the relevant study results and discuss how these results contribute to the current literature base of teacher professional noticing and responsive teaching.

Research Question 1

The goal of my first research question is to understand how teachers' responsiveness to student thinking shifted during our five-year PD program focused on student thinking. The question states, in what ways does teachers' responsiveness to student thinking shift during an extended professional development program with a focus on students' scientific thinking? Prior studies have shown that teachers who teach responsively are able to attend and respond to student thinking in order to support deep science learning (Hammer et al., 2012; Levin et al., 2012). If teacher professional noticing is an important precursor to responsive teaching, I suggest that a PD program with a focus on teacher professional noticing, should lead to developments to responsiveness to student thinking.

I used Lineback's (2014) redirections framework to examine teacher responsiveness to student ideas. I examined five classroom videos for each participant spanning the five-year PD program. Through my redirections analysis, I found that teachers were minimally responsive to their students' ideas in the classroom videos. This is evidenced by only one responsive activity redirection identified in Mr. Sanchez's data set and 17 total responsive focus redirections across all three teachers. In contrast to this, I identified 102 not responsive activity redirections and 13 delayed responsive or not responsive focus redirections across all three participants. When considering these totals, it is apparent that the teachers in this study were primarily engaging in not responsive redirections in their classrooms.

Due to the high number of not responsive activity redirections, I found that it was important to distinguish these redirections. I identified five different not responsive activity redirections in my dataset: 1) whole class discussion, 2) individual students developing or revising their explanations or models, 3) individual students completing surface level tasks, 4) small group or partner discussions, and 5) conducting observations or investigations as a whole class or in groups. It was previously concluded that responsive teaching supports students in engaging in science practices (Hammer et al., 2012). When I consider the not responsive activity redirections I identified in my results, four of the five are reflective of important science practices; discourse, modeling and explanations, and observation and investigation. Through my analysis, I found that Mr. Sanchez engaged in all five not responsive activity redirections (A2) and was the only participant to engage in the A2 redirection accounting for students developing or revising explanations or models. I found that Mrs. Hollander and Mrs. Packer primarily engaged their students in A2 discussion (whole class and small groups) and A2 engaging in observations or investigations.

The results of my redirections analysis do not provide evidence for growth in responsiveness over our five-year PD program. This is true for all three participants in my study. This is inconsistent with the results currently reported, which suggest that PD focused on student thinking supports teachers in becoming more responsive to student ideas (Levin et al., 2009; Lineback, 2014; Maskiewicz and Winter, 2012). My redirections analysis allowed me to understand teachers' instructional practices, examine these practices over time, and begin to draw comparisons across teachers (Lineback, 2014).

Research Question 2

My second research question seeks to draw a relationship between teacher professional noticing and responsive teaching. This question states, in what ways do teachers grow in relation to their professional noticing skills and their responsiveness to student thinking, during the course of a five-year professional development program focused on student thinking?

As I explained in response to research question one, I did not identify growth in teacher responsiveness over the course of the five-year PD program. What I did find is that my analysis of responsive teaching allowed me to identify the science practices that students engaged in in the participants' classrooms over the five-year study. Using the results from my redirections analysis, I considered my results from the genetics noticing task. I considered only the genetics noticing task to draw comparisons between teacher professional noticing and responsive teaching because this task depicted teacher-student interactions, whereas the sound professional noticing task would require the participants to make inferences about the teacher-student interactions.

Overall, I found that the not responsive activity redirections that teachers engaged in appeared to parallel the things that they reflected on in the genetics noticing task. Both Mrs. Hollander and Mrs. Packer primarily engaged in not responsive activity redirections around discourse. Additionally, they both reflected on discourse in response to the noticing task. In Mrs. Hollander's response to the teacher professional noticing task, she advances in the ways that she talks about discourse. In 2013, Mrs. Hollander talked about the students in the genetics video making sense of the phenomenon through discussion. In 2016, Mrs. Hollander talks about the students using models to engage in discourse about the phenomenon. And finally, in 2018, Mrs. Hollander talks about how students engage in discourse about using and revising models and explanations. These responses parallel the redirections results for Mrs. Hollander. Mrs. Hollander engages in not responsive activity redirections of whole class and small group discuss in all five years of my study, with the highest code count found in year five. This may suggest that Mrs. Hollander's increased complexity around noticing discourse in the classroom may relate to her increased engagement in discourse related redirections.

Similarly, Mrs. Packer increased in the complexity that she talks about discourse in response to the genetics noticing task. Mrs. Packer begins by describing the teacher as a facilitator of discourse in 2013. In 2016, she describes the teacher using probing questions to guide students. Finally, in 2018, Mrs. Packer describes the teacher as using probes to support students in making their own sense of the phenomenon. Mrs. Packer consistently engages in the not responsive activity redirection for whole class discourse across all five years of the study, with the highest code count in 2017-18. In three out of the five years, Mrs. Packer engages in the not responsive redirection engaging in investigation. While Mrs. Packer's students engage in investigations in her classroom, she visits the table groups probing them with important questions that target or guide student thinking. When considering the results for the genetics professional noticing task and my responsive teaching data, it seems that Mrs. Packer's increased complexity in thinking about how the teacher supports discourse through probing may be related to the prevalence of discourse and investigation redirection codes present in Mrs. Packer's own classroom teaching.

Mr. Sanchez was the only participant who engaged in the not responsive redirection for developing or revising models and explanations. This seems to relate to how Mr. Sanchez develops in his discussion about modeling over the course of the study in response to the genetics professional noticing task. In 2013, Mr. Sanchez describes the computer simulation the students are using to examine the phenomenon. In 2016, Mr. Sanchez acknowledges that this computer simulation is a model that the students are using to make sense of inheritance. In the final year, Mr. Sanchez explains that the students use and revise models, using the computer simulation to make sense of inheritance. Over time, Mr. Sanchez's responses in regards to modeling on the genetics noticing task become more complex, he grows from talking about a simulation to talking about that simulation as a model that can be revised. I identified the not responsive activity redirection for modeling in 2014-15, 2015-16, and 2016-17. The presence of this code grows from 0 codes in 2013-14, to 1 code in 2014-16, to 2 codes in 2016-17. I suggest that the increasing presence of the modeling redirections in Mr. Sanchez's classroom analysis may be related to the increased complexity in which Mr. Sanchez considers modeling in the teacher professional noticing task.

It seems that the not responsive activity redirections are most clearly connected to the responses to the genetics professional noticing task in my study. Namely, I found similarities in what the teachers reflect on in response to the genetics noticing task and the not responsive activity redirections identified in their classroom videos. These not responsive activity redirections (A2) are reflective of important science practices that the teachers in my study have their students engage in (discourse, investigation, and modeling). Hammer and colleagues (2012) previously reported that responsive teaching supports student engagement in science practices. Although these A2 redirections are considered not responsive to student thinking, they represent important science practices that these teachers engage their students in.

Previous studies have found that PD with a focus on student thinking support teachers in becoming responsive to student ideas (Levin et al., 2009; Lineback, 2014; Maskiewicz and Winter, 2012). This conclusion is not supported by the results of my study. While the three teachers in my study engaged in a five-year PD with a focus on student thinking, all three teachers did not appear to increase in their responsiveness to student thinking, as evidenced by minimal growth in responsive activity and focus redirections. The PD program in the current study used teacher professional noticing as a way to support teachers in their attention to student thinking. Prior studies have demonstrated that teacher professional noticing skills are challenging to develop and are not developed in the same way across participants (Amador et al., 2017; Jacobs et al., 2010, van Es et al., 2017; van Es and Sherin, 2008). While I was able to note growth in the teacher professional noticing tasks, I did not observe growth in the same skills across participants. This messiness in developing teacher professional noticing skills may have contributed to not observing growth in responsiveness to student thinking over time.

Research Question 3

My third research question sought to understand what teachers pay attention to when observing their own classroom teaching. This question states, during instruction, what instructional moments do teachers identify as critical moments, and how do these moments relate to teachers' responsiveness to student thinking? In order to address this question, I engaged in one semi-structured interview with each participant. During the interview, we watched one of the classroom videos that they had submitted during the PD program between 2013 and 2018. When I asked teachers to identify which moments of instruction they found interesting or important, the teachers reflected on at least two of the following categories: 1) evaluation of teaching practices, 2) explanation for why specific teaching decisions were made, and 3) attention to content taught or learned. Similar findings were reported by Dyer and Sherin (2015) and Johnson and colleagues (2017). Dyer and Sherin (2015) reported that during interviews, teachers reasoned about student thinking and the structure of particular tasks. Johnson, et al. (2017) also conducted interviews, reporting that teachers considered how students would interpret different tasks.

Mrs. Hollander spent a large portion of our interview evaluating her teaching practices. She considered issues such as whether her instructions were clear, whether she was leading her students too much via questioning, and whether she was allowing her students to engage in important sense-making or providing her students too much information. Mrs. Hollander also spent some time considering whether students achieved the content goals of her lessons. She considered to what extent students understand the content that they are being presented with. Mrs. Packer spent about equal time in our interview considering why she made specific instructional decisions and giving attention to the science that the students in her classroom were learning. Mrs. Packer explained instructional decisions like why she chose to further probe for specific student ideas, why she sequenced the lesson in a particular way, and why she had students revisit a previously watched video. In relation to content, Mrs. Packer often explained either the science ideas that the students were presenting or explaining to what extent students understand a particular content idea. Finally, I found the Mr. Sanchez engaged in evaluation of teaching practices, explaining instructional decisions, and reflecting on the science content that students learned. In evaluation of his own teaching, Mr. Sanchez asked questions about the clearness of instructions, whether the assignment could be used to assess student thinking, and the accessibility of certain tasks. Mr. Sanchez spent time explaining why he chose to paraphrase particular student ides, how he evaluated students' learning or attention, and why he chose to highlight particular student ideas when resuming whole class discussion. Finally, Mr. Sanchez considers how he elicited student thinking in-the-moment and evaluated whether the students learned the desired science content.

Evaluation of teaching practices and why specific teaching decisions were made are reflective of the results reported by Dyer and Sherin (2015) and Johnson et al. (2017). These authors report that teachers reason about instructional tasks, including considering the structure of instruction and how students will interpret specific tasks. My results support these findings because the teachers in my study evaluated the effectiveness of instructional decisions or tasks and explained why they made particular teaching decisions. Dyer and Sherin (2015) also found that teachers reason about student thinking, this finding is supported by my results in that the teachers in my study also considered science content that was being learned in their classrooms.

It is important to note that each of the three teachers in my study spent time in our interview considering the science ideas that students were raising and whether their students learned the science content being taught. Similar findings were reported in the literature on teacher professional noticing. At least three prior studies report that teachers evaluate student understanding of content (Kisa and Stein, 2015; Sun and van Es, 2015; Talanquer et al., 2015). And two studies report that teachers describe student ideas (Amador et al., 2016; Talanquer et al., 2015). These results suggest that the teachers in my study use a lens of teacher professional noticing and/or responsive teaching while analyzing their own classroom videos. Additionally, these interviews occurred in the fall of 2020, 1.5 years following the end of our PD program (summer of 2018). It is positive to see that these teachers are still engaging with student thinking 1.5 years after engaging in this long-term PD program.

Discussion

The majority of the literature published on teacher professional noticing and responsive teaching examine these skills in in-service elementary teachers or pre-service teachers. The present study contributes to this literature base by examining a different group of teachers, in-service secondary science teachers. My study is also a five-year longitudinal case study. The current literature examining teacher professional noticing and responsive teaching have not yet examined noticing skills or responsiveness in the same teachers across an extended period of time.

While my study showed that teachers grow in their professional noticing skills over time, my results did not show that growth in noticing skills corresponds with growth in responsiveness to student ideas. Through my analysis of teacher professional noticing and responsive teaching, I identified a possible relationship between growth in teacher professional noticing skills and the not responsive activity redirections that teachers engage in. These not responsive activity redirections are reflective of important pre-planned instructional activities that support student engagement with important science practices. More specifically, I found that growth in teacher professional noticing may be related to the prevalence of discourse, investigations, and modeling that teachers have their students engage in in their classrooms.

Limitations

It is important to recognize the limitations of the present study. There are important limitations in regards to both my teacher profession noticing and redirections analyses. One limitation in relation to my teacher professional noticing data collection is that none of the three participants in my study actively teach genetics in their classrooms. Mrs. Hollander teaches high school chemistry, Mrs. Packer teaches middle school integrated science, and Mr. Sanchez teaches middle school life science. By not teaching genetics content year after year, it is possible that level in which these teachers are able to pay attention to content and science ideas is limited. I would expect that individuals who engage with genetics content consistently may be more likely to identify key vocabulary and content ideas mentioned in the genetics video, which would contribute to an easier ability to engage in the teacher professional noticing skills. Being less familiar with a particular content area would contribute to a more difficult time engaging in the challenging practices of teacher professional noticing.

A second limitation for my analysis of teacher professional noticing is in relation to using teacher professional noticing tasks and a coding scheme. By administering a task, with a shortened classroom video or a small sample of student work, we are reducing the opportunity that a teacher is able to engage with student thinking. By providing more stimuli for teachers to engage with, it is possible that teachers may increase the extent to which they engage in the teacher professional noticing skills. Additionally, by using a coding scheme, I am selectively looking for particular patterns in the data, while purposely ignoring other aspects of the data. It is likely that by using our coding scheme, I was unable to account for important nuances in the data. For example, when I look at the results of the genetics noticing task for Mr. Sanchez using the coding scheme, I can see whether and how Mr. Sanchez shifted in the total number of codes for each teacher professional noticing skill over time. What these numbers do not show is that Mr. Sanchez talked about modeling in increasing complexity across the five years of the PD program. These nuanced differences can be important when considering how Mr. Sanchez grew in his ability to attend, interpret, or respond to student thinking. While reducing stimuli for a task or using a coding scheme for analysis are useful research strategies, it is important to consider how these strategies may impact my results.

Next, I want to consider the limitations of my responsive teaching analysis. First, my analysis of responsiveness only examines one video per year for each participant. This allows me to create a snapshot of each teachers' responsiveness per year. If I examined multiple videos of a lesson segment or a full unit, I may be able to observe and account for more responsiveness to student thinking in my data. I believe that this may be true because it would increase the likelihood of seeing how teachers refer to different student ideas over a series of lessons and whether teachers refer back to different student ideas over time. By only watching one video per year, I am unable to see how teachers engage with their students and content during consecutive class days.

Second, by using a coding scheme like redirections, I am limiting my analysis. The redirections analysis examines teachers' responsiveness in whole class settings only. I must acknowledge that it is possible that my redirections analysis is ignoring other responsive activities that teachers engaged in in my dataset. Namely, I did not examine teachers' responsiveness in small group settings or one-on-one with a student. For example, Mrs. Packer engaged in the not responsive activity redirection, engaging in investigation. In 2015-16, Mrs. Packer's class engages in a card sort activity of biotic and abiotic factors. As she goes around to the table groups, Mrs. Packer asks many questions and engages in discussion with her students. One notable moment is when she visits a group who is having difficulty sorting one of the cards, Mrs. Packer asks this group to shift from doing the card sort to watching a video in order to support their thinking. This is an important instructional move that Mrs. Packer makes in response to the ideas that her students raise, however, because the redirections analysis examines what happens in whole class settings, this moment was not coded for.

Future Directions

One of the primary next steps I would like to perform is to continue adapting the redirections coding framework. Lineback (2014) developed this framework to examine whole-class discourse in an elementary classroom. I would like to continue to adapt this coding scheme to account for redirections that occur when the teacher engages in talk with small groups present in their classroom. Because of the large number of small group activities I found in my dataset, I think it is probable that I would be able to observe more responsive redirections if I continued coding small group discussions or investigations that occur in table groups. As I previously described in my limitations section, I saw at least one example of this in Mrs. Packer's 2015-16 classroom video. When conducting this analysis, I would need to also consider if the redirections that are coded for in the whole class setting are the same or different than the redirections coded for in the small group setting.

An additional research area that I would like to consider is the methodologies used for teacher professional noticing and responsive teaching. When examining the literature on these two research areas, I found they use a variety of techniques and overlap in two, interviews and examining classroom discourse. If we are to better understand how teacher professional noticing and responsive teaching relate, it seems important to better understand how these research areas employ the same methods but use slightly different lenses for analysis. For example, Russ and Luna (2013) (teacher professional noticing) and Dyer and Sherin (2015) (responsive teaching) conduct interviews where teachers self-record their classrooms, selecting interesting moments to capture and then debrief in interviews afterwards. Russ and Luna (2013) report that teachers pay attention to classroom pedagogy, science practices, and teacher content knowledge. Whereas Dyer and Sherin (2015) report the types of instructional reasoning teacher engage in. A future study examining the relationship between teacher professional noticing and responsive teaching should use similar methodologies, and consider the relationship between the results using both research lenses.

Finally, I am interested in what teachers, who have engaged in extended PD, do following a particular PD program. I think it would be interesting to continue collecting data from the participating teachers, as well as collecting information on other formal development programs they may engage in, whether they conduct lesson study at their school site, continue their education, etc. In collecting this post-PD data, we can observe whether and how teachers maintain or change in their teacher professional noticing skills or responsiveness to student ideas, after ending an extended PD program. It would also be important for us to know how and whether teachers are still actively working to engage with students' scientific thinking.

Concluding Remarks

When I consider the lenses of teacher professional noticing and responsive teaching in relation to my own analyses, I see that teacher professional noticing allows me to account for all of the different things that teachers pay attention to. Responsive teaching, namely redirections, allows me to account for the instructional decisions that teachers make. My teacher professional noticing analysis allowed me to consider what the teacher sees when observing a classroom video or looking at student work. While my responsive teaching analysis allowed me to consider the different actions teachers take to support learning.

I have only begun to illustrate the relationship between teacher professional noticing and responsive teaching through this study. Namely, the relationship I identified is that the not responsive activity redirections teachers engage in in their own classrooms seems to relate to things they pay attention to when engaging in a professional noticing task. For example, Mr. Sanchez who increasingly engaged in more modeling redirections considered modeling in increasingly complex ways over the course of the five-year PD program.

Both teacher professional noticing and responsive teaching require skills that let students be heard and listened to in our classrooms. By actively considering the ideas that students bring into the classroom and how their ideas shift over time, teachers can better engage and support their students. While engaging in these skills has been found to be challenging, we must acknowledge that learning science is also a challenging task. By creating an environment where our students are heard, we make science more accessible and equitable.

Acknowledgements

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Appendix A: Genetics Noticing Task

1. Everyone views instructional situations differently. What 3 aspects of this video did you find noteworthy?
    2. Pretend that you are the teacher of this lesson.
        a. What is the most important thing for students to learn in this segment?
        b. Do you think they learned it? (Why or why not?)
        c. How might you assess the student understanding?
3. Please describe in detail and provide your reaction to what the different students did to make sense of the anomalous (to them) data they found (be as specific as you can).
4. Please describe and provide your reaction to what the teacher did as the students were making sense of the anomalous (to them) data.

Video adapted from Carpenter and Romberg (2004): https://drive.google.com/open?id=0B-VlXaNe_reyMGN0UGlJYXlhUzA

Student work samples for the genetics noticing task follow the next three pages.

Biology
Genetics
Unit 3

Examples

Heterozygous
x
Homozygous Dom
=
50% RR
50% Rr
100% Red

Heterozygous x
Homozygous recessive
=
50% Rr
50% rr
50% Red

	R	r
R	RR	Rr
r	Rr	rr

Heterozygous
x
Heterozygous
=
25% RR
50% Rr
25% rr
75% Red

	R	R
r	Rr	Rr
r	Rr	Rr

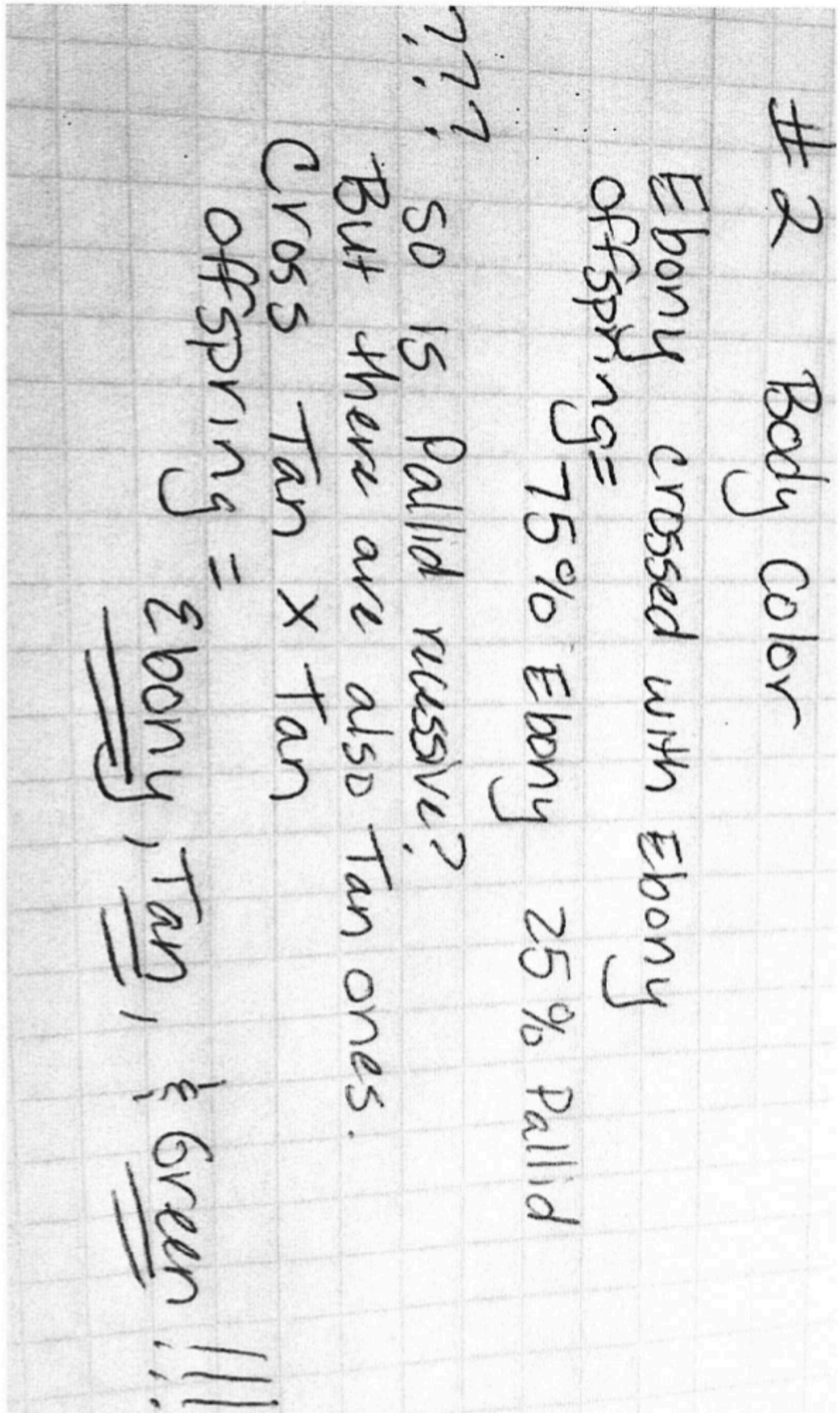
100% Rr
100% Red

Problem #1 Data Wing Shape

cross ♀ curved x ♂ curved
all offspring curved

cross ♀ curved x ♂ short
all wavy

cross ♀ short x ♂ short
all short



#2 Body Color

Ebony crossed with Ebony
offspring =
75% Ebony 25% Pallid

??? So is Pallid recessive?
But there are also Tan ones.
Cross Tan X Tan
offspring =
Ebony, Tan, & Green!!!

Appendix B: Sound Noticing Task

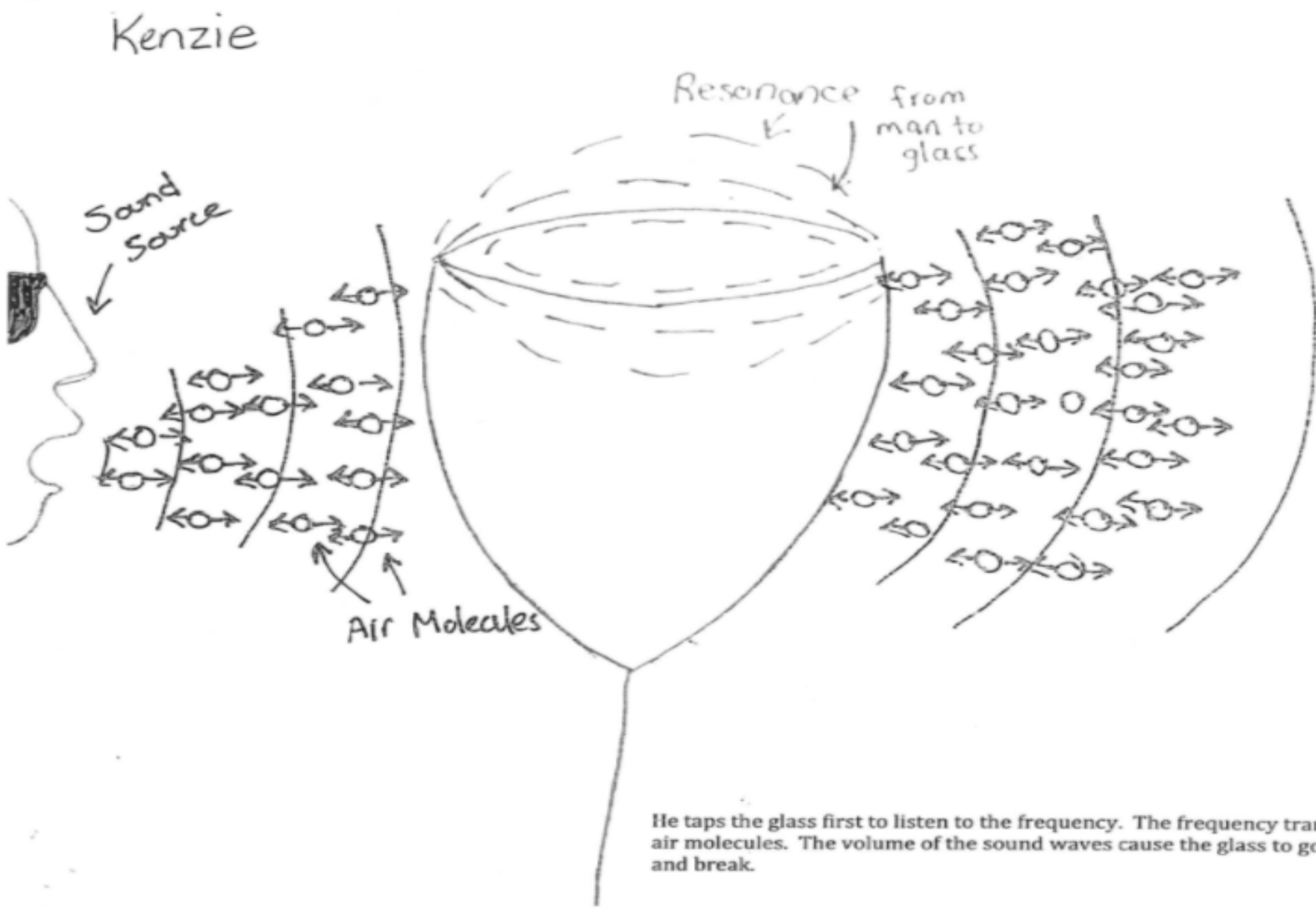
The students completed a model to share their ideas about sound. Markers, poster paper and pencils were available for students to use. We have provided you with three students' models. The models included words and drawings. We have re-typed the students' writing when it wasn't adjacent to the picture. Examine the student work. Then, individually, please respond to the 3 questions.

1. Please describe in detail what you notice about each child's work.
    a. Susana
    b. Kenzie
    c. Amy
2. Explain in detail what you believe you have learned about each child's ideas/understanding about sound.
    a. Susana
    b. Kenzie
    c. Amy
3. Pretend you are the teacher of these students. What instructional decisions would you make for the next lesson(s). Explain your rationale. Why would you decide to do this?

Student work samples for the sound noticing task follow on the next three pages.

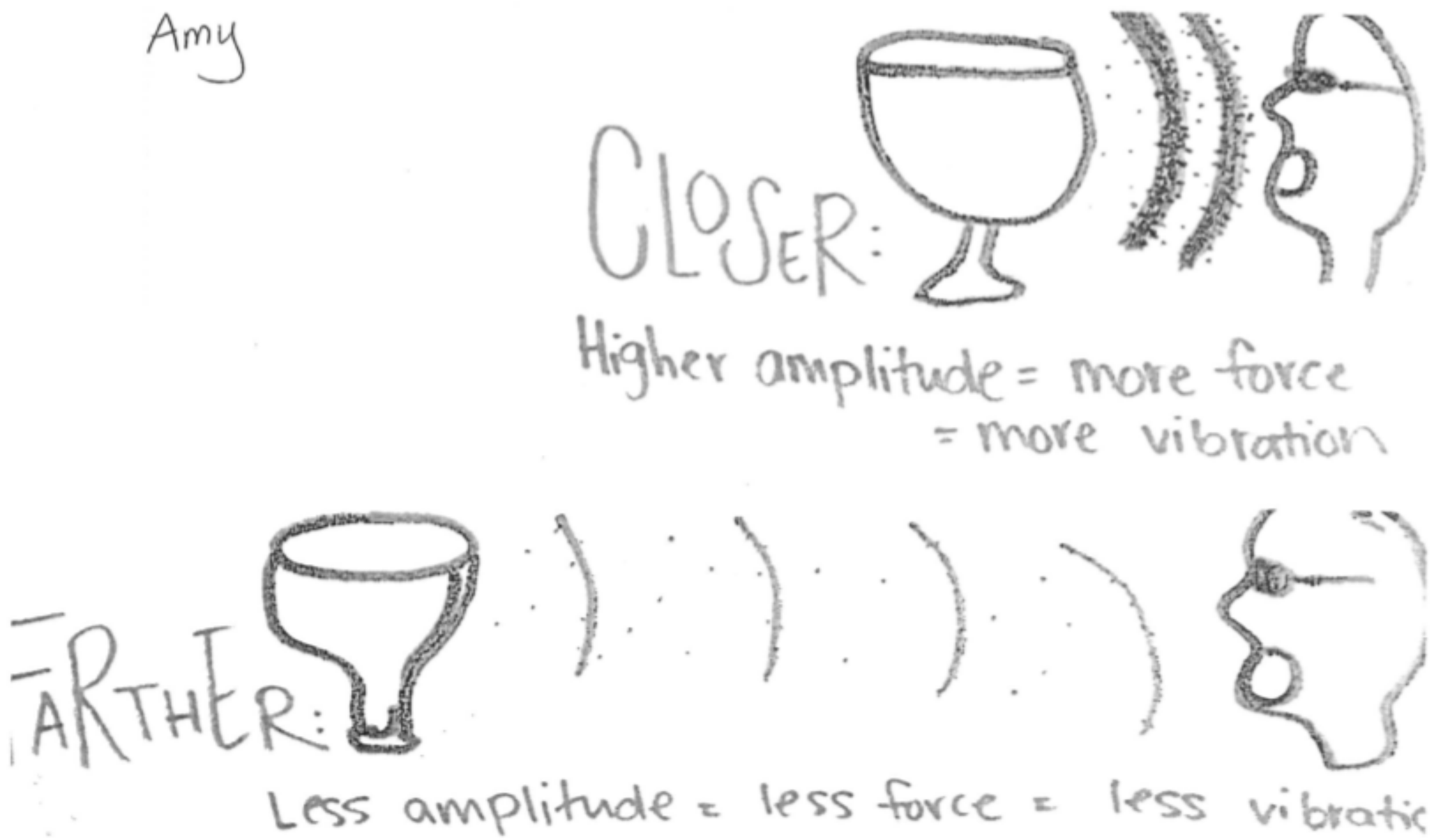
Susana

The sound is getting filled up into the cup (gathering the waves). The voice vibrates the cup. All the vibration causes the glass to shatter (the depth of the cup can't contain all the vibration/pressure).



He taps the glass first to listen to the frequency. The frequency transfers between air molecules. The volume of the sound waves cause the glass to go back and forth and break.

He taps the glass to listen to the pitch. Pitch is like frequency. With more amplitude and frequency the same as the frequency of the glass, it will vibrate. The longer this sound pushes on the glass, the more the glass vibrates and breaks.



Appendix C: Redirections Coding Scheme

Adapted from Lineback (2014).

Code name	Code description	Example of code
Activity – A1	Evidence that the teacher's redirection is grounded in the students' comments	Let me get a gauge of what we're thinking here. [T reads the boards] What's funny is, anyone notice that on the advantage. We said all the full of carbohydrates, which is sugar. But then on the disadvantage. A lot of you said disadvantages that are full of sugar. (2015 Sanchez, Pos. 63)
Activity – A2	No evidence that the teacher's redirection is grounded in the students' comments	
A2 – Whole class discussion	Students switch from one activity to an activity to engaging in whole class discussion with the teacher and other students	Okay, let's come back together, please. So, if you think that the top one represents butter, raise your hand. Oh! Okay! That's a pretty big consensus between the groups. (2013 Hollander, Pos. 18)
A2 – Individuals develop/revise explanations/models	Students switch from one activity to engaging in writing/revising explanations or developing/revising models	I want to give you guys a chance to revise and edit your conclusions. We had a question that said, why does the heart rate increase during exercise. What do the other systems themselves need to explain why. Be specific. (2014 Sanchez, Pos. 26)
A2 – Individuals complete surface level tasks	Students switch from one activity to engaging in individual work (i.e. completing a worksheet, exit ticket, reading a handout)	Please list three different ecosystems that you're aware of. the names of three ecosystem. (2017 Sanchez, Pos. 3)
A2 – Small group/partner discussion	Students switch from one activity to discussing ideas in pairs or table groups	Talk at your groups, what was her claim and what evidence did she present. (2014 Hollander, Pos. 23)
A2 – Observation/investigation as whole class or in groups	Students switch from one activity to engaging in observation or investigation of a phenomenon as a whole class or in table groups (i.e. observing a phenomenon through video, laboratory activity or card sort)	But what I am going to do is, I am going to give each table is set of cards. And inside your card pack, there's biotic factors for the environment and there's another card somewhere in there that says abiotic. I think it's actually right behind this one... Abiotic factors and every other card in here is a list of something. (P continues giving instructions on card sort activity) (2015 Packer, Pos. 50)

F1 – Responsive	Clearly grounded in the students' comments in the last/most recent exchange	
F1 - TRM	Requests students to explain, exemplify, or identify a term	Okay, so let's have somebody else help me here, then, can someone tell me how you could describe an isotope to someone who has never taken chemistry? What might you say? (2016 Hollander, Pos. 7)
F1 - REP	Requests student to repeat a comment made previously	*Teacher invites a student to repeat a previously made comment.*
F1 - MIN	Is minimally or tangentially related to student comment(s)	H: What happens if you leave it out for like an hour? What happens to the bacon fat? **S3: It like solidifies on the skillet.** H: And is it still see through? (Class: No.) No, it's kind of opaque, right? Okay, so we're thinking about the different food sources might have something to do with this. Okay? **Can anyone tell me why a solid... Sort of how the molecular structure of a solid is different... Think about the atoms when we talked about how they were moving.** Class: Oh! [students talking inaudible - heard tight together, vibrating] H: Sliding over each other, right? So, we talked about solids vibrating and liquids moving over each other. (2013 Hollander, Pos. 10-14)
F1 - MOR	Requests students extend/elaborate student comment(s) in a specific way	*Teacher asks for elaboration in some way – requesting evidence, justification, etc.*
F1 - CON	Requests the students consider/reason about student comment(s)	*The teacher asks a student what they think of another's comment or idea.*
F2 – Delayed responsive	Clearly unconnected to the students' comments in the last exchange by seek to revisit, discuss, and/or elaborate something previously raised	The rodent population will increase if there are no owls, right? So that's no good either, is it? Necessarily... Depending. What do you think that this has to do with ecology, evolution, and genetics. (2013 Packer, Pos. 14)
F3 – Not responsive	Does not appear to be connect to students' comment/idea/work	So, I want to show you another model that I made to help us understand beta decay. I want you to think about is it better or worse than this model and what sort of things is it missing, what things can we add to it. Okay. (2015 Hollander, Pos. 30)

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