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Examining teachers' goals and classroom instruction around the science and engineering practices in the Next Generation Science Standards

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Examining Teachers' Goals and Classroom Instruction Around the Science and Engineering Practices in the Next Generation Science Standards

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by

Jarod Kawasaki

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ABSTRACT OF THE DISSERTATION

Examining Teachers' Goals and Classroom Instruction Around the Science and Engineering Practices in the Next Generation Science Standards.

by

Jarod Kawasaki

Doctor of Philosophy in Education

University of California, Los Angeles, 2015

Professor William A. Sandoval, Chair

This qualitative study examined teachers' described and observed classroom instruction around the science and engineering practices in the Next Generation Science Standards (NGSS). Seven secondary science teachers were surveyed and interviewed about their understanding and use of the science and engineering practices in their classroom teaching and then were observed to document their actual use of these practices. This study sought to describe (1) the variety of goals that teachers pursue in their classroom instruction and (2) the variety of instructional strategies teachers use to pursue those goals. Findings suggest that there were varying degrees of alignment between the teachers' described and observed classroom instruction and between their classroom instruction and the goals of the NGSS. For example, it was easier for many teachers to

describe instruction around the science and engineering practices that aligned with the goals of the NGSS than it was to enact instruction that aligned with the NGSS. I suggest that the difficulty teachers experienced with enacting these practices emerged from teachers' misunderstanding of and misalignment with the goals of the NGSS. In order to address the challenges teachers faced in incorporating the science and engineering practices into their classroom instruction, I recommend some key features of professional development that may support teachers in refining their understanding, goals, and classroom instruction around these practices.

The dissertation of Jarod Kawasaki is approved.

Noel Enyedy

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2015

This dissertation is dedicated to Christine, Hannah, and Andie.

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Chapter I: Introduction and Statement of the Problem

"Educational change depends on what teachers do and think—it is as simple and as complex as that" (Fullan, 2001, p. 117).

With the national adoption of the *Next Generation Science Standards* (NGSS, Achieve, 2013) practitioners and researchers have become increasingly concerned with finding ways to support teachers in designing classroom instruction to meet the goals of the NGSS (Pelligrino, 2013). The NGSS emphasize a set of science and engineering practices that are a drastic departure from the content knowledge emphasis in the previous *National Science Education Standards* (NSES, NRC, 1996). These science and engineering practices are informed by previous research on how students learn (Bransford, Brown, & Cocking, 2000) and productive disciplinary engagement in science classrooms (Engle & Conant, 2002; Ford & Forman, 2006; Lehrer & Schauble, 2007). The emphasis on these science and engineering practices, though, presents new concerns and issues. For example, helping educators deeply understand the vision, organization, and goals of the NGSS, including the science and engineering practices, is an imperative first step to developing high quality curriculum materials (Pruitt, 2014). Given these challenges, the success of this new policy initiative may hinge on providing teachers with support in understanding the goals of the NGSS and designing instruction to meet those goals (Garet, Porter, Desimone, Birman, & Yoon, 2001; Spillane, Reiser, & Gomez, 2006).

At the forefront of these supporting efforts will be a variety of professional development opportunities for educators focusing on specific areas of the NGSS. After many years of studying professional development and teacher learning, researchers have developed a comprehensive list of effective professional development attributes, such as sustained engagement (Gess-Newsome & Lederman, 2001), content specificity (Garet, et al., 2001), and building communities of practice (Loucks-Horsley & Stiles, 2001). We have long known, though, that one-time or even short-term professional development sessions are often ineffective at supporting changes in teachers' classroom instruction (Moon, Michaels, & Reiser, 2012; Penuel, Fishman, Yamaguchi, & Gallagher, 2007).

More recently, researchers have closely examined how repeated cycles of assessment of practices and outcomes can be an effective way to design long-term professional development (Moon et al., 2012; Penuel, Fishman, Cheng, & Sabelli, 2011; Penuel & Fishman, 2012). Research examining these long-term professional development studies and recent research in novice teacher learning document salient features of how teachers learn to teach differently, specifically understanding the influence of the contexts teachers work in (e.g., school, community) (Allen & Penuel, 2014; Thomspon, Windschitl, & Braaten, 2013) and the social and cultural practices that shape learning opportunities (Jurow, Tracy, Hotchkiss, & Kirshner, 2012). These studies have also called for more robust theories about teacher learning grounded within everyday classroom practice.

Teachers face a tremendous challenge in re-orienting their teaching around the science and engineering practices in the NGSS in a short amount of time. The NGSS demands that students take on a majority of the responsibility for making sense of scientific ideas (their own and other peoples) and their science learning experiences. These demands necessitate a shift towards designing instruction that promotes student discourse and provides students with multiple opportunities to share and revise their ideas. This shift is reasonably difficult given that this new way of teaching and learning is likely in competition with the ways teachers learned science as students in secondary and post-secondary schooling, the pedagogical approach they learned in their teacher credential program, and the ways they have been teaching with the previous standards. Research is needed to develop models and resources to support teachers in learning how to create and foster these new learning opportunities for students around the science and engineering practices in the NGSS. The goal of this study was to identify ways to support teachers in their effort to incorporate the science and engineering practices. To pursue this goal, I analyzed teachers' described and observed classroom instruction around the science and engineering practices in the NGSS in order to understand the goals that teachers pursued within their instruction. Examining the successes and struggles teachers described and experienced while incorporating the science and engineering practices into their classroom teaching and understanding the goals they pursued during classroom instruction, revealed opportunities to support them in their efforts meet the demands of the NGSS.

I take a situated perspective in order to identify teachers' goals through their classroom instruction (Brown, Collins, & Duguid, 1989; Hutchins, 1995; Lave & Wenger, 1991). This perspective grounds my investigation of teachers' everyday classroom teaching and views teachers' instruction as the coordination between their content knowledge, goals, and practices. From this perspective, these elements are tied to the situations in which they occur and, thus, are difficult to tease apart. Therefore, it was necessary to identify teachers' goals from their reflections about their teaching, classroom artifacts (e.g. lesson plans, student work), and observations of classroom teaching (Sandoval, 2012). Triangulating between teachers' reflections, classroom artifacts, and classroom observations, as opposed to relying on a single information source, provides a more complete picture of the goals that teachers pursue through their classroom instruction. This situated perspective guided my investigation into how teachers attempted to incorporate novel approaches to support student participation in the science and engineering practices in the NGSS by triangulating between teachers' knowledge of these practices, the goals they pursued with these practices, and reflections about their classroom teaching around these practices.

In this study, I documented the various ways teachers described and enacted the science and engineering practices in their classroom teaching. My primary aims were to identify teachers' goals, understand how those goals manifested themselves during classroom teaching, and identify productive ways to support teachers in refining their classroom instruction to better align with the goals of the science and engineering practices in the NGSS. I documented new and/or modified instructional activities that teachers described and used to provide students with opportunities to take responsibility for their own science learning experiences, encourage student participation in the processes of science, and promote student discourse during classroom instruction. In my findings, I describe how teachers' classroom instruction at times aligned with the goals of the NGSS and also how they were at times in competition with them. My discussion frames these findings in terms of the potential opportunities to support teachers' efforts to incorporate the science and engineering practices and the potential implications for the design of professional development during the implementation phase of the NGSS. Findings from this study can inform the development of more robust theories of teacher learning grounded in the everyday practice of classroom teaching. This study asked the following research questions:

1. What goals do teachers pursue in their described classroom instruction around the science and engineering practices in the NGSS?
2. How do teachers incorporate the science and engineering practices into their classroom instruction?

Chapter II: Background on the Problem

My interest in understanding how to support teachers' efforts to incorporate the science and engineering practices in the NGSS into their classroom teaching is motivated by the drastic changes around teaching and learning in the NGSS. Teachers are expected to adopt and enact the NGSS in a short amount of time. Research is needed to develop models and resources that support teacher learning around understanding the goals of the NGSS and then enacting those goals in their classroom instruction.

Theoretical Framework: Situated Cognition

From a situated perspective, learning and thinking are rooted in participation within historically-shaped communities and through bodies, tools, perceptions, community norms, and social interactions (Barsalou, 1999; Lave & Wenger, 1991; Hutchins, 1995). The situated approach considers not only the individual as the unit of analysis but also the full activity within which participation occurs. Within this framework, researchers have examined the relationship between mind and body (Streeck, 2009), person and environment (Clark, 2008), person and tool (Vygotsky, 1978), and person and social other (Lave & Wenger, 1991).

Cognitive scientists interested in teacher education have long depicted teaching as a continuous act of high-level cognition that is driven by goals that emerge within particular contexts (Borg, 2003; Borko & Livingston, 1989; Bransford, Sherwood, Vye, & Rieser, 1986). Through this situated perspective, teaching has been viewed as continuous iterations of reasoning, thinking and problem solving on the most appropriate ways to ensure student learning (Bransford et al., 1986). The goal of teaching becomes what the teacher wants to accomplish. It is imperative, though, to acknowledge that features within the context (e.g. tools, social norms) largely inform the goals of the participants (e.g. teacher) within the activity (Brown et al., 1989;

Hutchins, 1995; Vygotsky, 1978). From this perspective, teaching is a difficult and complex practice of coordinating between the goals for teaching, knowledge required to teach, the practices that meet the needs of students, and the resources available within the classroom.

The fundamental aim of this study is to inform how teachers learn to teach differently. I approach this problem from a situated perspective that views learning to teach with the same complexity that has been associated with the actual act of teaching. Learning to teach differently requires coordination between new content knowledge, goals, practices, and resources. The situated perspective guides my investigation into how teachers learn to incorporate novel approaches to support student participation in science and engineering practices by triangulating between teachers' knowledge of these practices, goals for incorporating these practices into their classroom instruction, and reflections about their classroom teaching.

Review of Relevant Literature

In this section, I examine the few theoretical and empirical studies that outline the goals and demands of the NGSS and then frame the challenge of adopting and enacting these goals around the research literature on the relationship between teachers' understanding of previous science education reform efforts (e.g., scientific inquiry) and their enactment of those reform practices. At the end of the section, I discuss specific gaps in this literature and needs within the science education research and practitioner communities and how this study attempts to address them.

Demands of the NGSS

When the National Research Council released the framework for the NGSS (NRC, 2011), practitioners began to ask why the shift from scientific inquiry to science practices (Bybee, 2011; Osborne, 2014). Bybee states that, "scientific inquiry is one form of scientific practice. So, the perspective presented in the framework is not one of replacing inquiry; rather, it is one of expanding and enriching the teaching and learning of science" (p. 14). While Bybee states that scientific inquiry is a component of the NGSS, the phrase "scientific inquiry" is actually used very sparingly in the framework and standards. It is plausible that the phrase scientific inquiry is not prevalent in the NGSS because previous research showed that teachers often enacted scientific inquiry in ways that unproductively led to misconceptions around the nature of science and scientific investigation (Bybee 2011, Chinn & Malhotra, 2002; Obsorne, 2014). Chinn and Malhotra (2002) argued that the types of inquiry that were occurring in classrooms produced knowledge and practices that epistemologically conflicted with the ways of thinking and knowledge that scientists build through inquiry. It seemed that inquiry tasks were oversimplified in textbooks and standardized curriculum leading to a version of inquiry with outlined procedures for students to follow and predictable outcomes for teachers to look for in student work, which is contrary to the typical work of professional scientists. Another contributing issue was that the "official" definitions of inquiry that teachers had to draw from themselves varied a great deal and were confusing (Abd-El-Khalick, Boujaoude, Duschl et al., 2004). The attempt to specify practices is an effort to move past that confusion. The NGSS represents an effort to outline the core practices that are involved in scientific inquiry, to give teachers and other educational stakeholders a clearer sense of what it really looks like to do science.

In the NGSS, there is a drastic shift in goals from the previous *National Science Education Standards* (NSES, NRC, 1996) focus on teaching rigorous content standards to a new emphasis on helping students participate in science and engineering practices. The NGSS views these science and engineering practices as conduits for students to simultaneously engage with and learn about science (Bybee, 2011; Osborne, 2014). The NGSS does not imbue the idea of a separation between science content and the processes of science—as did the NSES by having a set of standards for investigation and experimentation separate from the content standards—but rather views these two as intimately integrated together. Bybee states it succinctly that "when students engage in scientific practices, activities become the basis for learning about experiments, data and evidence, social discourse, models and tools, and mathematics and for developing the ability to evaluate knowledge claims, conduct empirical investigations, and develop explanations" (p.14). Viewing science content and the processes of science as integrated comes with a new set of demands and goals for teachers to understand and incorporate into their teaching. From my review of the theoretical literature around the NGSS and findings from an expert review panel study (Kloser, 2014), there seem to be three major demands for teachers in the NGSS, (1) deeply understanding the goals of the science and engineering practices, (2) managing and organizing student talk, and (3) shifting the responsibility for learning to students.

Deeply understanding the goals of the science and engineering practices. Previous research shows how teachers' goals, beliefs, and understandings about science education reform influence the ways they enact the goals from the reform (Aguirre & Speer, 1999; Coenders, Terlouw, & Dijkstra 2008; Crawford, 2007; Davis, 2008; Haney, Czerniak, & Lumpe, 1996; Keys & Bryan, 2001). Asking teachers to modify their classroom instruction to be in alignment with the expectations of a reform movement necessitates opportunities for teachers to examine and confront their own goals in relation to the goals of the reform movement (Bryan, 2012).

Given that the goals of the NGSS are drastically different from the NSES, teachers need to develop a deep understanding of the goals of the NGSS in order to enact them (Pruitt, 2014; Reiser, Berland, & Kenyon, 2012). Osborne (2014) states that the science and engineering practices contain different goals that serve different purposes (i.e. developing students' epistemic versus procedural knowledge). Supporting teachers' understanding of each goal and their specific purpose will support them in designing classroom instruction and making these goals explicit for students.

Examining teachers' initial understanding of the goals of the NGSS provides a baseline for designing professional development activities and can inform subsequent interactions (e.g., informal discussions, classroom observations, interviews) with them (Crawford, Capps, van Driel et al., 2013). Professional development activities can then aim to align teachers' goals with the definitions and goals outlined in the NGSS (Allen & Penuel, 2014; Moon et al., 2012).

Managing and organizing student talk. Promoting student discourse is a major feature within the NGSS and was identified as a core practice among expert science teachers and university faculty (Kloser, 2014). According to Kloser, facilitating classroom discourse includes classroom practices such as "sharing of evidence- and/or model-based explanations and arguments; and encourages students to take up, clarify, and justify the ideas of others" (p. 1197). These types of discourse align with the goals of the NGSS.

In addition, the science and engineering practices in the NGSS are viewed as "language intensive and require students to engage in classroom discourse" (Lee, Quinn, & Valdes, 2013, p. 22). Re-organizing classroom discourse to increase students' role in productive scientific talk has shown promise in improving science learning (Furtak, Seidel, Iverson, & Briggs, 2012; Michaels, O'Connor, & Resnick, 2008; Minner, Levy, & Century, 2010; Schroeder, Scott, Tolson, Huang, & Lee, 2007). While engaging in these types of practices and discourse can be difficult for students, some evidence has shown that students are capable of quite sophisticated scientific reasoning with appropriate guidance and support (NRC, 2007). For example, children have learned to argue scientifically with sustained instruction focused on discursive practice

(Kuhn, Zillmer, Crowell, & Zavala, 2013; Lehrer, Schauble, & Lucas; 2008; Metz, 2011; Ryu & Sandoval, 2012). Teachers, though, have struggled with promoting student argumentation in their classrooms (McNeil, 2009) and with incorporating these discursive approaches to support student argumentation (McNeil, Lizzote, Krajcik, & Marx, 2006; Simon & Maloney, 2006). This practice-centered view of instruction is drastically different from current educational practice, which focuses on students learning the science concepts and theories apart from the practices that led to them. The NGSS, thus, poses a significant challenge for science teachers, as they demand new ways of thinking about designing and providing instruction (Pruitt, 2014).

The science and engineering practices in the NGSS incorporates the work from many years of science education research around productive and meaningful engagement in science classrooms (Engle & Conant, 2002; Ford & Forman, 2006; Lehrer & Schauble, 2006; Windschitl, Thompson, Braaten, & Stroupe, 2012). A unifying idea through this research is that productive student discourse is required. The science and engineering practices include discourse-intensive goals such as having students evaluate the work and ideas of their peers, articulating their initial ideas about scientific phenomena and revising them as their knowledge on this phenomena develops (e.g., scientific modeling), investigating their own scientific questions and interests (i.e. design and carry out experiments, analyze data, communicate findings), and using evidence when constructing explanations and engaging in argument. Effectively designing opportunities for teachers to learn how to promote productive student discourse in science classrooms will be an imperative component to the success of this new reform initiative.

Shifting learning responsibility toward students. Another major feature of the NGSS is that students take on a majority of the responsibility for making sense of their own ideas and science learning experiences. This idea weaves through many of the core science teaching practices identified by experts in Kloser (2014). For example, practices such as engaging students in investigations and constructing and interpreting models indicate that teachers should identify ways to support students in designing, constructing, and planning investigations and developing models.

Berland and Reiser (2009) frame student responsibility around meaningful participation, where students revise their own arguments in order to resolve discrepancies and inconsistencies, rather than because the teacher asked them to do so. Others have discussed student responsibility through a practice-based view of science education, where students engage in practices common to professional scientists (Duschl & Bybee, 2014; Duschl & Grandy, 2013; Osborne, 2014). The NGSS demands that students take more responsibility for their own learning experiences, participating in the science and engineering practices in order to learn about science content (Bybee, 2011).

Given these new and drastically different demands, empirical research is needed around teachers' understanding and enactment of the science and engineering practices to meet these new goals (Allen & Penuel, 2014; Moon et al., 2012). Professional development offers an opportunity to leverage teachers' initial understanding of the goals of the NGSS to promote teacher reflection and sustained sense-making around areas of incoherence between their understanding and the actual goals of the NGSS (Allen & Penuel, 2014; Crawford et al., 2013). Studies are needed that describe the variability of teachers' understanding and enactment of the science and engineering practices in order to inform the development of models and resources for teacher learning in professional development.

Links and Disconnects Between Teachers' Described and Observed Classroom Instruction

The new demands of the NGSS suggest that teachers need to re-focus their goals and learn to incorporate new instructional approaches into their classroom teaching. Presumably, deeply understanding the goals of the science and engineering practices might lead to productive enactment of those practices in science classrooms. Some have recently argued that developing teachers' understanding of the goals of the NGSS should be a key component of professional development because it will support teachers in designing instruction to meet these goals (Pruitt, 2014; Reiser et al., 2012). There has been some debate, though, about the links (or disconnects) between how teachers talk about their classroom teaching (i.e. reflection of their understanding of goals) and their actual classroom teaching (i.e. enactment of those goals). Some have attributed the inconsistency to research that has ignored the context-dependent nature of teachers' instructional goals (Mansour, 2009). It seems imperative for researchers to develop tractable and valid ways to identify teachers' instructional goals if professional development designers are committed to developing teachers' understanding of the goals of the NGSS with the hope that it influences teachers' classroom instruction.

In this section, I report on previous literature around the links and disconnects between teachers' understanding and instructional goals and their actual classroom practice. I argue that a practice-based approach is the most appropriate way to identify teachers' instructional goals. This approach requires triangulating between teachers' reflections about their teaching and classroom artifacts (i.e. professed instructional goals) and observations of actual classroom teaching (i.e. enacting those goals) (Sandoval, 2012). First, though, I provide some context around this previous literature that uses *teachers' beliefs* as the construct under study. I view teachers' beliefs about teaching and learning as a reflection of teachers' instructional goals.

There is a large body of literature around scientific inquiry that examines the relationship between teachers' beliefs about teaching and learning and their actual classroom instruction. The term "beliefs" is a widely defined construct (for a comprehensive review of definitions, see Table 35.1 in Jones & Carter, 2007). The research interest in teachers' beliefs during the past 30 years of research around scientific inquiry largely stemmed from "the assumption that beliefs are the best indicators of the decisions individuals make throughout their lives" (Pajares, 1992, p. 307). There has been some evidence that teachers' beliefs about teaching and learning mediate their instructional practice (Coenders et al., 2008; Crawford, 2007; Davis, 2008), yet there seems to be some be some disagreement about the direction and magnitude of the relationship between beliefs and classroom instruction (Mansour, 2009). For the purposes of this section, I view teachers' beliefs about teaching and learning as a reflection of their understanding of and/or goals for teaching and learning. Some have viewed teachers' beliefs in a similar manner (Brickhouse, 1990; Crawford et al., 2013, Kane, Sandretto, & Heath, 2002).

Consistencies between beliefs and instruction. A substantial amount of the literature on teachers' beliefs is concerned with teachers' epistemological and pedagogical beliefs because it is widely believed that these beliefs impact instructional decisions (for comprehensive reviews, see Fang, 1996; Jones & Carter, 2007; Pajares, 1992). A main assumption throughout this literature is that teachers seem to hold strong beliefs about knowledge and the nature of knowing (e.g. epistemological beliefs) that impacts their beliefs about teaching and learning (e.g. pedagogical beliefs) (Prawat, 1992). Science education researchers have found that teachers who hold naïve beliefs about the nature of science (e.g. science knowledge as absolute and used to find the 'truth') also hold beliefs about how to teach science that include prescriptive approaches where students follow procedural steps in their investigations and are asked to recall simple science facts and concepts (Brickhouse, 1990; Lederman, 1992). Whereas, those teachers who hold more sophisticated beliefs about the nature of science (e.g. contested, open-ended, and tentative) are more apt to hold beliefs about teaching and learning that include instructional approaches such as inquiry-based investigations and evidence-based decision-making (Brickhouse, 1990; Bryan, 2003; Lederman, 1992).

As a result of this research, others have sought to examine whether teachers' epistemological and pedagogical beliefs predicts their classroom instruction (Brickhouse, 1990; Hashweh, 1996; LaPlante, 1997; Tsai, 2002). For example, in her seminal article on science teachers' beliefs and their relationship to classroom instruction, Brickhouse identified a relationship between the ways that teachers thought about the nature of scientific theories, the scientific process, and scientific progress and the instructional practices teachers employed in their classroom. One finding from Brickhouse's study was that a teacher who held the belief that the scientific process was purely inductive, modeled student interactions with science around linear and iterative activities (e.g. scientific method). Whereas, a teacher who viewed the scientific process as theory-driven observation and experimentation, built instruction around inquiry activities where students supported historical scientific ideas using their personal observations and experimentation.

Another example of particular salience for this study is Tsai's (2002) identification of three themes for teachers' beliefs about teaching and learning: traditional notions (e.g. transferring knowledge from teacher to student), process notions (e.g. focused on problem-solving procedures), and constructivist notions (e.g. helping students construct knowledge). Tsai found that teachers' notions about teaching and learning were often aligned (i.e. traditional notion of teaching and a traditional notion of learning) and influenced teachers' perceptions of appropriate practices in their classroom. Along the same line, Hashweh (1996) found that teachers who held constructivist teaching beliefs effectively used a large repertoire of practices that encouraged students to develop alternative explanations to science problems more so than teachers who held empiricist beliefs.

These studies demonstrate that a relationship between beliefs and classroom instruction exist, yet they cannot claim that the relationship is unidirectional or causal. Mansour (2009) argued that researchers have largely underestimated the complexity of the relationship between beliefs and instruction because of the intertwined nature of knowledge, beliefs, and teaching. Mansour argues, instead, that researchers should treat teacher beliefs as context dependent and inseparable from their prior experiences. A situated approach considers the contextual factors that might influence teachers' beliefs about teaching and learning and their classroom instruction. I next turn to studies that demonstrate an inconsistent relationship between teachers' beliefs about teaching and learning and their practice, focusing on studies that have examined contextual constraints that mediate this relationship.

Inconsistencies between beliefs and instruction. Debates within educational research about the relationship between beliefs and classroom instruction can be attributed to poor conceptualization of teacher belief as a construct (Pajares, 1992) and the complex and intertwined nature of knowledge, beliefs and teaching (Mansour, 2009). These two papers highlight plausible reasons for the inconsistencies in the relationship between beliefs and classroom instruction that I discuss below, citing additional empirical studies that support their argument.

Pajares (1992) argued that poor construct conceptualization of 'teacher belief' in research relating beliefs and classroom instruction led researchers to neglect potential contextual factors that may cloud the relationship. It seems that these contextual features can either provide the infrastructure for teachers to pursue teaching that aligns with their beliefs or they can constrain teachers' ability to align their beliefs and classroom instruction. A few educational researchers have paid close attention to some of these contextual factors (e.g. people, physical environment, expertise in teaching, personal and educational experiences with science) that may constrain teachers from enacting classroom instruction that aligns with their beliefs (Haney, Lumpe, Czerniak, & Egan, 2002). Subsequently, Haney and her colleagues have conducted extensive research identifying various contextual factors that seem to influence teachers' beliefs, classroom instruction, and teachers' intentions to implement science education reform (Czerniak, Lumpe, & Haney, 1999; Haney, Lumpe, & Czerniak, 1996; Haney, Lumpe, & Czerniak, 2003; Haney et al., 2002; Haney & MacArthur, 2002; Lumpe, Czerniak, & Haney, 1998; Lumpe, Haney, & Czerniak, 2000; Lumpe, Czerniak, Haney, & Beltyukova, 2012). For example, Milner, Sondergeld, Demir, Johnson, and Czerniak (2012) suggest peer and administrator expectations influenced teachers' classroom instruction more so than teachers' changed beliefs about science education reform practices.

Much of this research has led to or used a framework that Haney and colleagues developed that separated beliefs into two categories—capability beliefs and context beliefs—in order to better understand these contextual constraints. Haney and colleagues define "capability beliefs [as] an individual's perception of whether he or she possesses the personal skills needed to function effectively. Context beliefs include an individual's perceptions about how responsive the environment (external factors and/or people) will be in supporting effective functioning" (p. 172). Dividing beliefs into these two separate categories allows for the investigation of the contextual constraints that influence teachers' classroom instruction. These studies suggest that the inconsistencies in the relationship between teachers' beliefs about teaching and learning and their classroom instruction arise from contextual features that either constrain the enactment of classroom instruction that align with beliefs or affords the alignment between beliefs and instruction.

If in fact the context matters as these studies have suggested, then Mansour's (2009) argument that beliefs are context-dependent (or situated, Prawat, 1992) is particularly salient to this study's aim of understanding teachers' instructional goals through their descriptions of the classroom teaching. Mansour calls attention to the sociocultural context that shapes teachers' beliefs and argues that it is difficult to study teaching and learning outside of the influence of culture and context given that teaching and learning are "situated in a physical setting in which constraints, opportunities or external influences may derive from sources at various levels, such as the individual classroom, the school, the principal, the community, or curriculum" (p. 32).

Many educational researchers have long argued for a situated approach to studying teaching and learning in order to account for variations from context to context and the multitude of contextual factors (e.g. student demographics, culture and identity, teacher training to name a few) that influence teachers' pedagogy and student learning (Brown et al., 1989; Erickson & Shutz, 1981; Lave, 1988). By taking this situated approach, researchers identify teachers' beliefs around teaching and learning through reflections on and observations of their classroom teaching. While a teacher may espouse certain beliefs about teaching and learning, those beliefs may not manifest themselves in their classroom instruction given contextual features such as time constraints, pacing plans, lack of resources and/or expertise. Inferring those beliefs (or goals) from teachers' reflections on and/or observations of their classroom teaching embeds those beliefs into the contexts in which they arise (i.e. context-driven) and thus might be a better reflection of a teachers' understanding of those goals.

There have been some studies that investigated the situative nature of beliefs about teaching and learning in relation to classroom instruction. Bryan (2003) and Windschitl (2003) argued that the relationship between teachers' beliefs and their classroom instruction was more aptly reflected in teachers' personal experiences with science. Windschitl showed that teachers who held deeply personal experiences with academic or scientific research, held more comprehensive views about inquiry and in turn those views turned up in their classroom instruction. Those teachers with little experience and less sophisticated views of inquiry did not change their classroom instruction, even after participating in a professional development session in which teachers conducted an inquiry project themselves. Windschitl suggested that limited exposure to inquiry (e.g. short-term professional development focused on a scientific inquiry project) was not enough to change teachers' views and in turn, affect their classroom teaching. In a similar light, Bryan argued that the tension between teachers' espoused beliefs and enacted beliefs was the extent to which the belief was grounded in personal experience. Bryan argued for a framework that viewed teachers' beliefs as nested where one nest exists within a teachers' day-to-day practice (enacted) and the other nest exists as a larger vision for classroom instruction (espoused). Bryan found that espoused beliefs were foundational to guiding instruction, but at times were overshadowed by contextual factors such as classroom management. Both of these studies indicate that the relationship between teachers' beliefs and classroom instruction is complex and may possibly vary between contexts and situations.

School and classroom contexts have been carefully examined to better understand the inconsistencies in the relationship between teachers' beliefs about teaching and learning and their classroom instruction. These investigations highlight how a variety of contextual factors either constrain or afford the alignment between teachers' beliefs and instruction. Kang and Wallace (2005) in their study of teacher beliefs about science laboratory activities, suggest that aligning beliefs about teaching and learning and teaching is a negotiation between teachers' beliefs, the teaching context and the teachers' instructional goals. Specifically, Kang and Wallace suggest that teachers' goals allow for or prevent the enactment of specific practices in the classroom. Aguirre and Speer (1999) in their study of math teachers' goals found that teachers' instructional goals mediated the enactment of particular beliefs through classroom instruction. Extensive research has been conducted on both teachers' beliefs about teaching and learning and the features of the teaching context (as mentioned above), but less attention has been paid to the relationship between teachers' instructional goals and their classroom instruction. It might be that teachers' beliefs are too broadly defined and, thus, difficult to operationalize, producing varied results when linked to classroom instruction. Instructional goals, though, is more easily defined—what a teacher is trying to do—and can identified through teachers' descriptions of their classroom teaching and observations of their actual teaching.

From my review of the relevant literature around efforts to support teachers' understanding and enactment of science education reform polices (e.g., scientific inquiry), it seems that in order for the NGSS reforms to have a long-lasting impact on classroom instruction, research is needed in two distinct areas. First, there is a need for research that understands the variety of goals that teachers pursue during classroom instruction, especially during teachers' efforts to incorporate the science and engineering practices. This type of investigation, though, must be grounded in teachers' reflections on their classroom instruction and observations of their actual teaching. Coordination between these two data sources provides a clearer picture about teachers' goals than previous research that has mostly relied on a single data source. This research will support the new reforms by informing the work of professional development facilitators and teacher educators about the links and disconnects between teachers' goals and the goals of the NGSS. Second, there is a need to clarify the relationship between teachers' goals and their classroom instruction. Taking a situated perspective on this relationship grounds the examination of teachers' goals in their daily classroom teaching. Clarifying this relationship contributes to theoretical perspectives on teacher learning highlighting the potential productiveness of re-focusing teachers' goals around the goals of the reform in order to refine teachers' classroom instruction. This study directly addresses this first research need and informs the latter.

Aims For My Study

This study aims to build on recent research around the developing framework of demands and goals in the NGSS and contributes to the limited but growing body of empirical research around teachers' understanding and enactment of the science and engineering practices in the NGSS. One important aim of this study is to describe the variety of goals around the science and engineering practices that teachers pursue and the classroom instruction they use to pursue those goals. This aim can inform current theories of teacher learning that view learning along trajectories (Jurow et al., 2012; Thomspon et al., 2013) by highlighting teachers' varying degrees of understanding of the goals of the NGSS. Understanding teachers' initial goals and instruction as well as how these goals and instruction vary highlights the need for differentiated professional development that meets the needs of a diverse group of teacher learners.

Another aim for this study is to inform theories of teacher learning by highlighting the importance of aligning teachers' instructional goals with the goals of the NGSS. Models and resources are needed to support teachers in learning how to teach differently (Lee, Miller, & Januszyk, 2014; Moon et al., 2012, Osborne, 2014). Finding links between teachers' instructional goals and their classroom practice can inform how professional development is designed. This study addresses this challenge by examining teachers' reflections on their classroom instruction and observations of their actual teaching. To my knowledge, few studies have examined teachers' goals through the coordination between teachers' described and observed classroom instruction.

My goal for this study is to learn about how to support teachers during this time of reform by collecting and analyzing data from the everyday practice of classroom teaching. Findings from this study responds to the need for models and resources to support teachers during the transition to the NGSS, by identifying salient features of learning that emerge from teachers' efforts to refine their classroom teaching as they incorporate the science and engineering practices and meet the demands of the NGSS.

Chapter III: Methods

In this study, I used interpretive qualitative research methods (Erickson 1986, Merriam, 2009) to investigate the following research questions.

1. What goals do teachers pursue in their described classroom instruction around the science and engineering practices in the NGSS?
2. How do teachers incorporate the science and engineering practices into their classroom instruction?

To answer these questions, I collected three data sources: an open-ended questionnaire about teachers' ideas about the science and engineering practices in the NGSS, open-ended interviews with each teacher about their efforts to incorporate science and engineering practices, and written field notes from classroom observations.

I did not set out to represent a generalized view of how teachers interpret the science and engineering practices from the NGSS, but rather to represent the goals and efforts of a small sample of teachers making an earnest attempt to incorporate the science and engineering practices into their classroom teaching. The aim of my study then, was to understand how teachers' goals aligned with the goals outlined in the NGSS and describe the variation in those goals as they unfolded in classroom teaching.

Study Context and Participants

This study took place in a small urban school district in a large metropolitan city in the southwest United States serving a student population that is 87% Latino, 68% of whom receive free or reduced lunch, and nearly a quarter of whom are English language learners. Teachers were recruited during a three-day professional development workshop at the beginning of the school year. During the professional development workshop teachers were introduced to the

NGSS, participated in model lessons around the science and engineering practices, and given time with school-based peers to collaborate and plan for implementing the NGSS into classroom teaching. The professional development workshop emphasized the science and engineering practices and the utility of creating more opportunities for students to take responsibility for their own learning experiences in science classrooms. I was involved with the design and facilitation of the professional development and became interested in following up with some of the teachers to examine their goals and classroom instruction around incorporating the science and engineering practices into their current classroom teaching. While it was intended that there would be periodic professional development sessions throughout the year, unforeseen circumstances prevented any subsequent sessions with teachers.

Five high school (3 women) and two middle school (1 woman) science teachers volunteered to be interviewed and observed for this study. The high school teachers came from the same high school and the two middle school teachers came from different middle schools. Participating teachers' teaching experience ranged from 6-32 years with an average teaching experience of 14 years. Teachers taught a range of different science courses including Chemistry, Biology, Earth Science, Anatomy and Physiology. Four of the seven teachers received their Bachelors degree in science and three of the seven teachers have a Masters degree in science education.

Data Sources

Three data sources were collected for this study. The professional development workshop occurred in August, during which I administered the science and engineering practices questionnaire. During October, I conducted open-ended interviews with the seven teachers. From October through March, I observed the seven teachers' classrooms and wrote field notes during my observations. In addition to field notes, I also provided feedback to teachers based on my classroom observations. This feedback typically occurred via email. Table 1 presents the timeline and design for data collection. At times teachers' lessons occurred over two days (as indicated in the table by 'O*'). In these cases, I counted the multiple days as a single observation. Of the seven teachers, five of them were observed three times, one of the teachers was observed twice, and one teacher was observed once. In total, I made 18 observations between the seven participating teachers.

Science and engineering practices questionnaire. This open-ended questionnaire contained a brief introduction to the task where I defined the word "practice" and asked teachers to describe what each of the eight science and engineering practices in the NGSS meant to them. Each practice was listed with a few empty lines for teachers to write a brief description of what each of the eight science and engineering practices meant to them and for their own students. All of the questions were handwritten and responses were transferred, verbatim, into a spreadsheet. The questionnaire as seen by teachers is presented in Appendix A.

Open-ended interviews. I used an open-ended interview protocol because these interviews were designed to be follow-up conversations with the teachers about how they understood and used the science and engineering practices in the NGSS discussed in the professional development workshop. Interviews began with an open-ended question that opened up a line of conversation about their classroom teaching since the professional development workshop. Interviews ranged from 12-38 minutes, with an average of 25 minutes. All of the interviews were conducted at the teachers' school site during their conference period, at lunch, or after school.

Table 1
Description of data collection timeline

Teacher	Grade	Content	August	October	November	December	January	February	March
Christy	HS	Chemistry	Q	N	O	E	O, E		O
James	MS	Physical Science	Q	N	O*	E	O	O	
Helen	MS	Life Science	Q	N	O*	E		O*	E, O
Jody	HS	Sports Medicine	Q	N, O	E		O		
Sharon	HS	Chemistry	Q	N	O, E	O		E	O
Joe	HS	Chemistry	Q	N	O*, E				
Simon	HS	Biology	Q	N	O*, E	O*		O	

Q: Questionnaire
N: Interview
O: Observation (O*: Two day observation)
E: Email feedback

Each interview started with a brief introduction that explained the purpose of meeting with each teacher. Teachers were told that the model of professional development was different yet untested and thus I wanted to collect data around how teachers experienced the professional development, challenges and successes, and their efforts to incorporate the science and engineering practices into their classroom teaching. I began all the interviews with the same initial question: "Tell me about any new activities or approaches you have used since the professional development workshop in August." This question inevitably led the conversation to the specific ways that teachers were trying out some of the science and engineering practices in their class. I often asked teachers to specifically discuss how they were teaching differently and what students were doing differently in class. During the conversation, I asked follow-up and probing questions such as "Can you tell me a specific example of how that looked in your classroom?" or "Tell me more about what you actually did during that lesson." This allowed me to have teachers discuss specifics around what they were doing and what they were having students do during classroom instruction. For five of the seven interviews, this opening request to discuss new activities sufficed to propel detailed conversations about what each teacher was doing around the science and engineering practices in the NGSS.

For the remaining two interviews (with Jody and Christy), my initial request to describe new activities did not lead teachers to provide much detail about their instruction. For these three teachers, I asked them which science and engineering practice their department decided to focus on. I returned their open-ended questionnaire responses and a copy of the science and engineering practices from the NGSS. I asked teachers to read their own response for their selected practice, read through the definition of that practice in the NGSS, and note any important differences between them. During the conversation, I asked follow up questions such as, “Tell me more about what you mean by that practice” to have teachers specifically discuss their ideas about the selected practice.

All the interviews were audio recorded and transcribed for analysis. Immediately after the interview, I wrote a few notes in an analytic memo describing my initial impression of how each teacher viewed the science and engineering practices in the NGSS. Interviews were transcribed within one day of the interview and in a fashion where grammar was corrected and interview noise (e.g., stutters, pauses) was removed (see denaturalism in Oliver, Serovich, & Mason, 2005). As I transcribed the interviews, I added to my analytic notes any features of each interview that stuck out to me as relevant to their ideas and goals around incorporating the science and engineering practices into their classroom teaching.

Classroom observations. Classroom observations were arranged between the teachers and myself. Observations were scheduled through teacher invitation on days where they were doing an activity they felt incorporated the science and engineering practices. Every few weeks I would email each teacher to ask when he or she was using an activity that was either new or aligned with the goals of the NGSS. In my email, I asked when they might be doing a lab, group work, or a whole class discussion. Teachers responded with a specific date and period that they wanted me to come observe. I adjusted my schedule to accommodate their request. Observations ranged from 55-120 minutes. All of the observations were conducted during school hours in science classrooms.

During observations, I took ethnographic field notes that included a chronological account of the instructional activities, teacher talk, and student talk that occurred during the observation. My focus during observations was on capturing as much of the teachers' interaction with students as possible. Capturing teachers' interaction with students would enable me to utilize my interview analysis to inform my analysis of observed classroom instruction. To do this, I documented the classroom context (e.g., number of students, participation structures), instructional activity set up by the teacher, and classroom discourse that occurred during the activity. During whole class activities, I typically sat in a corner of the classroom and wrote field notes. During small group activities, I followed the teacher for 3-5 minutes in order to listen to the conversations he/she had with groups of students and then returned to a computer to record those conversations and interactions.

In addition, there were conversations (in person and via email) with the teachers that occurred either during the observation or in between observations about details, goals, or expectations of class activity. These conversations were often informal feedback sessions where teachers asked me for my thoughts on the lesson I observed. I emailed all seven teachers after my first classroom observation. I took these opportunities to provide suggestions and feedback to help teachers refine their lessons and instructional activities. My feedback was based on my understanding of the NGSS and previous research literature on productive ways to support student engagement and participation in science classrooms. When these conversations occurred during classroom observations, I immediately wrote a summary of the discussion in my field notes. I also kept all email exchanges with the teachers. I exchanged additional emails with a few of the teacher depending on the situation and their responsiveness to the feedback.

Institutional Review

This study complied with guidelines set forth by the UCLA Institutional Review Board to ensure the safety and welfare of human research subjects involved in the study. Teachers gave their informed consent to participate after being apprised of the process, constraints and confidentiality of the study. All personal identifiers were removed from the data and pseudonyms were used for all participants in the study. Questionnaire responses, interview transcripts and observation field notes were labeled with teacher identification numbers developed for this study. A password-protected document was kept that linked the participants and their identification number. Digital audio recordings and video recordings were deleted after transcription and data analysis.

Data Analysis

My analysis of teachers' responses to the questionnaire, descriptions and observations of the classroom teaching were informed by underlying ideas and conceptions of good science teaching. I acknowledge that I have some preconceived ideas about the productive ways to teach the science and engineering practices and applied these notions to my analytic frame when developing codes and themes from my data. My analysis of data was divided into two stages organized by my two research questions.

Defining teachers' goals. I defined teachers' goals from a situated perspective. From this perspective, teachers' goals were bound within a specific context (e.g., classroom teaching) and evident in both teachers' ideas about the science and engineering practices and their descriptions of how they utilized those practices as classroom instructional strategies. I acknowledge that simply asking teachers what each of the science and engineering practices means is only one source of data that may reflect their goals. Therefore, I inferred teachers' goals from their descriptions of their efforts to incorporate the science and engineering practices into their classroom teaching. My interview data served as the primary data source for examining teachers' goals.

RQ1: What goals do teachers pursue in their described classroom instruction around the science and engineering practices in the NGSS? The first stage of analysis was used for the interview transcripts to understand the specific goals teachers pursued in their efforts to try new approaches to teaching science. For this data, I used a latent thematic analytic approach (Braun & Clarke, 2006) to identify teachers' goals from their descriptions of their efforts to incorporate the science and engineering practices from the NGSS. I used this approach to look for themes and patterns within a specific data item (e.g., interview transcripts) and made connections to these underlying ideas about teaching.

To answer this question, I analyzed teachers' descriptions of their classroom teaching from the open-ended interviews. My analysis was informed by the implicit and explicit goals from the NGSS and previous research literature around productive instructional approaches to engage students in these practices. To identify the goals of the NGSS, I repeatedly read through the descriptions of the science and engineering practices in the NGSS. The purpose of these readings was to identify the essential features outlined in the NGSS for each science and engineering practice. Based on my understanding of previous science education literature that these practices were based on, I identified 2-3 essential features of each practice (see Appendix B).

The first step in analyzing the interviews involved repeated readings through the interview transcripts to gain a general understanding of different approaches teachers used to incorporate the science and engineering practices into the classroom teaching. I used Atlas.ti, Version 6.2 (Atlas.ti Scientific Software Development GmbH, Berlin, 2010-2011, www.atlasti.com) to organize and code interview transcripts. My goal was to code a majority of the data, leaving as little of the transcript as possible as un-coded through this first analytic cycle. From this first set of readings, I identified 19 different instructional strategies and activities teachers described during the interviews. In this initial step, I used the most basic elements of the data (teachers' descriptions of their classroom teaching) as codes (Braun & Clarke, 2006). Next, I read through the quotations for each code and developed a definition and clear example for each code. From this list of 19 instructional strategies, the next step was to identify broader ideas (themes) that could categorize these 19 codes. I began to think more specifically about what the teachers were trying to accomplish through these instructional strategies and approaches (e.g., teachers' goals). I categorized the 19 codes into 16 different goals that teachers pursued in their classroom teaching. The goals were informed by my understanding of the science and engineering practices in the NGSS.

I decided to code the original transcripts—without my previous coding scheme—because I wanted to generally document the goals that teachers pursued without being influenced by instructional strategies I had coded previously. Again, I tried to code the majority of the data, leaving as little of the transcript as possible as un-coded. Once I coded all the transcripts, I read through the quotes for each goal. During this reading, it seemed that there was some overlap between goals. For example, it seemed that the goal of *not giving students answers* and *building students confidence* were features of *scaffolding students taking more responsibility for their learning experiences.* Thus, the quotes for these first two goals were subsumed into the latter. Also, I found that teachers talked about relevance in two specific ways, *how science could be exported into the students' everyday lives outside of school* and *how everyday experiences could be imported into school to help students learn*. Initially, there were four different goals that teachers pursued around relevance, but I ended up collapsing them to create these two goals. After this refinement, I ended up with 12 goals that teachers pursued in their descriptions of their classroom instruction around the science and engineering practices.

The next step in my analysis was to organize these goals by common themes. I identified these themes using my understanding of the goals of the NGSS and organizing teachers' goals according to these themes. I identified four themes around the goals of the NGSS, (1) student thinking (i.e. eliciting students' ideas), (2) student responsibility (i.e. having students take responsibility for their own learning experiences), (3) student participation (i.e. getting students to participate in the science practices), and (4) student relevance (i.e. making science relevant for students). Each goal was categorized into a theme. For example, *eliciting students' initial ideas about a science topic*, *assessing students' science knowledge from a prior lesson,* and *having students explain their understanding of a science phenomenon* were classified under the theme of student thinking. A list of the four general themes, the corresponding goals, the definitions for each goal, and example quotations for each goal is reported in Table 2.

Table 2

Analytic themes and teachers' goals identified from descriptions of their classroom instruction from interview transcripts.

Theme/Goal	Definition (code)	Example
Student thinking		
Elicit students initial ideas about science content	Teacher discusses wanting to provide (or providing) students with opportunities to discuss their understanding of a science topic before the teacher has taught the material.	Yeah, once they understand the process. But I would like to do more at the beginning, before I start telling them anything. I am working on how to incorporate that. And you know, it really depends on the kids. Some classes I could walk out of and not worry.
Assess students recall of science knowledge	Teacher discusses instructional activities where students write or speak about their understanding of the science content covered in class	**Christy**: And also when they are doing work, we do homework here. Because they have to show me that they get it, own it like I said. And then something I am doing this year is after every classwork, I ask the kids to go over it. **Jarod**: Like the discussion you were talking about **Christy**: Yes, a lot of discussion I add since.
Have students explain their understanding of a scientific phenomena	Teacher discusses instructional activities where students are pressed to explain their thinking around a science topic or problem	Put it into your words and right away the kids want to grab the book and give me the definition, but I say no, tell me, I always play the role, I am 9 years old, I have no idea about chemistry and I ask you, what is this? And they give me whatever they wrote from the book and I say, but why? I act like that. Why, what do you mean? I force the kids to be the teachers. And another kid will add something else and by the end we discuss and talking and giving examples and teaching me. I do that a lot, I let them teach.
Student responsibility		
Scaffold student autonomy, freedom, agency with strategies	Teacher discusses specific strategies they have used to support students in figuring out the content themselves	**Sharon**: I told them put the knowns, you have the periodic table, you have the knowns down and then figure out where the holes are and start placing them and they were like, this is hard. and you know, I was like yeah, well where should they go? well, your the one who has to figure that out. Think about Mendeleev, he didn't even have the periodic table to have those knowns. **Jarod**: Essentially, he had all these characteristics and features **Teacher**: And he had to figure it out just using characteristics. At least you have a head start.

Scaffold student autonomy, freedom, agency with knowledge	Teacher discusses providing some background content knowledge to support students in figuring out new content for themselves	**James:** But I'm not sure if any of us are sold on the idea of them discovering it for themselves. Some, like if you taught A, B, and C and they figure out D, as opposed to trying to figure out A, B, and C on their own. **Jarod**: Right, like the folks who discovered the atom, didn't start with nothing. **James**: Yeah, exactly **Jarod**: They had a huge base of knowledge about the world around them that help them **James**: Right, right, that's kind of my philosophy, so seeing it done differently, I am open to, but sometimes when I see it, I am a little skeptical.
Use peer collaboration to support student autonomy, freedom, agency	Teacher discusses how they design participation structures, explicitly teach collaboration, and/or have students work together to support them in figuring out content for themselves.	**James:** when they are preparing the warm up, projects or labs, I'll have them work in groups of four. The high achieving kid and there is usually a kid who needs help **Jarod:** Heterogeneous groups **James**: Yeah, definitely, it works out, I try to balance it out so that they group leader doesn't do all the work and just tutor, but in reality they do a lot of tutoring. There isn't a good way to get around that.
Have students understand it is acceptable to make mistakes	Teachers discuss how they are communicating to students that it is acceptable to get things wrong in science	It is ok if they get something wrong, which is pretty hard for them to get. When I get kids their original idea is that they don't want to say anything unless I know I am right and then my system is if you don't say anything then you aren't trying and there is a consequence for it, but if you get it wrong, that is ok.
Student participation		
Slow down instructional pace	Teachers discuss the need to slow down the instructional pace in order to spend time on the science and engineering practices	But that is a challenge because of this brutal pace, pacing guide was driving things, so we end up doing part of a lab, spending less time on things. Now we can maybe slow down.
Teacher designs/controls science practices	Teacher describes instructional activities where students participate in science and engineering, but largely designed and controlled by the teacher	**Christy**: Developing and using models, definitely, especially for chemistry that would be great. And also, the carrying out investigations, **Jarod**: Can you tell me about the models? Have you tried to use this one? **Christy**: For example, instead of talking about chemical reactions, putting on the board the chemical reaction, I give to the students paper clips with different colors and I have a reaction of water decomposition, I have water becomes hydrogen and oxygen. I will give the paper clips, different colors one for hydrogen and one for oxygen, and when the reaction happens, they can see that I have the same number of atoms, but there is no water anymore. They still have 2 hydrogens, things like that. Definitely we are trying to use more representations.

Student designs/controls science practices	Teacher describes instructional activities where students design/control their participation in the science and engineering practices	So but I thought, I am going to give this a shot. Normally I would go and demonstrate how to wrap a shoulder, they already know internal and external rotation, I would show them the position, give them the sheet, demonstrate and then have them go back and do it and come and look at each persons and then send them back. But instead of doing that I said ok, I want you guys, you know this is external rotation and this is internal rotation [demonstrating the movements with her own arms], I want you to prevent external rotation. You have this wrap and this piece of tape, you don't want them to do this [external rotation]. I created this situation where is someone walked into the training room and you know, Go. You have tape and a wrap. And you know, it was so fun, so fun to watch, and they really came up with some creative things, some of them I said they would never be able to put their uniform on if they did that, but you did what I asked you to do. Others came up with a general shoulder splint. The thing that was so amazing was that they next time, I gave them some feedback, no look what you did, they were thinking about the direction of pull all these things that normally I am telling them and they don't get, and when we did the opposite activity, I said now, they seem to have a much greater understanding of that, but I wasn't 100% sure, but we did the opposite, I want you to prevent internal rotation, and 95% of the kids did it right the first time. They positioned them correctly, there was such a greater understanding of what they were trying to do versus me telling them how to do it.
Student relevance		
Use everyday situations to help students learn science content	Teacher discusses using real-world examples to help students understand science content	Plus, they want to know about aliens and life on other planets. I can always go back to this [discussion of light travel from the sun], we can do things to Mars but we can't change where the sun is. So how, if we need to terraform Mars, what can we do about the light. And a lot of these kids have parents who garden, so I ask what kind of plants do grow.
Depict how science applies to other situations	Teacher describes how science is useful in out of school contexts such as future occupation and/or decision-making	Understand what they are going to be expected in the job market, because most jobs, some of them you'll go out and have procedures, their bosses will say just do this and find this.

RQ2: How do teachers incorporate the science and engineering practices into their classroom instruction? In the second stage of my analysis, I used the themes from my interview data analysis to analyze my field notes from observations of classroom teaching. Next, I wrote detailed case studies (Creswell, 1994) for each teacher to provide a chronological account of my interaction—observations, informal conversations, and email correspondence—with each teacher throughout the school year. The purpose in developing case studies was not necessarily to show change over time, but rather to describe each observation and highlight my interactions with teachers. These case studies were, then, analyzed to understand and identify patterns within and across teachers.

To answer this question, I organized my analysis of teachers' classroom teaching around the goals identified from the interview transcripts. I conducted my analysis of interview transcripts first in order to generate an analytic lens for analyzing field notes from my observations of teachers' classroom instruction. My goal was to describe the variety of classroom instruction that teachers used to incorporate the science and engineering practices, especially as they related to the goals they said they were pursing. In addition, I described my interaction with teachers throughout the school year. During classroom visits and over email, I discussed with teachers, their classroom instruction during my observation. Over time, it became apparent that there were not going to be any additional professional development sessions and my role as researcher evolved, eventually becoming a resource for teachers to discuss their teaching and ideas around the NGSS. I included my interactions with teachers throughout the year in my analyses to depict the potential of providing feedback to teachers grounded in observations of their actual classroom teaching to help them refine their instruction around the science and engineering practices.

The first step in analyzing the field notes from classroom observations was to repeatedly read through the all field notes for each teacher. During these readings, I used the four general themes identified from my analysis of the interview transcripts to code the field notes categorizing the instructional strategies that teachers used during my observations of their classroom teaching. I also used an ‘other’ theme for any strategies that did not seem to fit under any of the four themes. This allowed me to remain open to any additional goals that emerged from the observation data. My aim was to have a majority of the data coded using these themes, leaving as little data as possible as un-coded through this first analytic cycle.

In the next step of my analysis, I read through the field notes for each teacher again and used the 12 goals from the interview transcripts to code the field notes from classroom observations. This analysis consisted of reading through teachers’ instructional strategies and trying to identify the goals they might be pursing through their teaching. For example, during a lab in class, a teacher might offer some background knowledge to help students construct an explanation for the phenomenon they observed in the lab. This would be coded as *scaffolding student autonomy with content knowledge.* Through this process, I found that a few of the codes did not manifest into actual classroom teaching during my observations. For example, *slow down instructional pacing* and *satisfy district, administration, or departmental demands* were goals that were not apparent in my observations of classroom teaching and therefore I did not use these codes in my analysis of field notes. In addition, *demonstrate the science practices* did not appear in my observations of classroom teaching, so, again, I did not use this code in my analysis of field notes. The purpose of this step in the analysis was to organize the variation in teachers' instructional strategies in order to compare and contrast them with the goals of the NGSS. Accounting for the variation in teachers' strategies allowed me to understand how teachers' approaches to incorporating the science and engineering practices differed across observations for each teacher and between teachers in the sample.

In my next step of analysis, I wrote detailed case studies for each teacher, describing the classroom context, instructional activity for the class period, and classroom discourse that occurred during each observation I conducted with each teacher. These case studies organized my data in a way that allowed me to examine the variation in classroom instruction within and across teachers. I also included any informal conversations—in person or via email—I had with each teacher. This chronological account of my interaction with each teacher allowed me to further examine the goals teachers pursued in their classroom teaching, how teachers' instruction varied across observations, how instruction varied between teachers in the sample, and whether or not teachers incorporated the feedback I provided to them.

In the final step of my analysis, I developed a sense of how teachers' described and observed classroom instruction aligned with the goals of the NGSS. For example, some teachers used modeling activities in order to have students explain their understanding of science content, whereas other teachers incorporated whole class discussions after labs. Identifying these similarities between teachers helped to compare and contrast the instructional strategies teachers used to pursue the same goal and examine how these strategies align with the goals of the NGSS.

Chapter IV: Findings

I began this study with two research questions, one that examined how teachers described their efforts to incorporate the science and engineering practices in the NGSS and another that examined how teachers actually tried to incorporate the science and engineering practices into their classroom instruction. My goal was to examine how teachers' described and observed instruction aligned with the key features of the science and engineering practices outlined in the NGSS. During my analysis, I began to develop separate notions of how teachers' descriptions of their efforts to incorporate the science and engineering practices aligned with the key features of these practices outlined in the NGSS and how their observed classroom instruction aligned with the key features of these practices outlined in the NGSS. I found that, expectedly, teachers varied in the ways they described and enacted the science and engineering practices. Independently, though, these notions only told part of the story. I began examining the ways in which teachers' descriptions of their classroom instruction around the science and engineering practices in the NGSS cohered with my observations of their classroom instruction around these same practices. What emerged from examining teachers' descriptions of their instruction in relation to my observation of their instruction was a tension in how teachers navigated their understanding of these practices in order to enact them in their classroom. This analysis revealed a larger narrative about the varying degrees in which teachers' described classroom instruction cohered with their observed classroom instruction and the degree to which teachers' classroom instruction aligned with the key features of the science and engineering practices outlined in the NGSS.

This chapter is divided into two sections. In the first section, I present my analysis of teachers' described classroom instruction in order to illustrate the variety of goals that teachers pursued and account for the ways that teachers' described instruction varied from one another. In the second section, I present case studies for each teacher, reporting selected excerpts from my observations of teachers' classroom instruction and the extent to which their observed classroom instruction cohered with their described instruction. When applicable, I describe my interactions with teachers throughout the year in order to illustrate how teachers incorporated feedback I provided to help them in order to refine their classroom instruction around the science and engineering practices. I use these case studies to make the argument that the variation between teachers represents varying degrees of alignment with NGSS. To support this argument, I organize these case studies around the coherence between teachers' described and observed instruction and their alignment with the goals of the NGSS.

Variation in Teachers' Described Classroom Instruction

In this first section, I present my thematic analysis of interview transcripts to depict the variation in teachers' described classroom instruction. In my analysis, I coded teachers' descriptions of their classroom instruction around the science and engineering practices in the NGSS and identified 12 goals that emerged across this sample of teachers (see Table 3). To organize this section, I grouped these goals into four common themes, (1) student thinking (i.e. eliciting students' ideas), (2) student responsibility (i.e. having students take responsibility for their learning experiences), (3) student participation (i.e. promoting student participation in the science and engineering practices), and (4) student relevance (i.e. making science relevant to students). Table 3 shows these goals grouped by each of these themes. Within each of these goals, teachers described a variety of classroom instructional strategies that pursued these goals.

Student thinking. Providing opportunities for students to share their ideas in science classrooms is an important feature of the NGSS. Teachers described various instructional strategies in order to encourage and promote student talk in science classrooms. In some cases, teachers focused on more traditional strategies where the goal was to *assess students' knowledge from prior lessons* or *press students to explanation their understanding of a science phenomenon*. In other cases, teachers' strategies were more aligned with the goals of the NGSS where they described the importance of *eliciting students' initial ideas about a science idea*. To depict this contrast, I selected quotes from interview transcripts of teachers' described classroom instruction.

James described using his warm-ups as a tool for assessing students' recall of science they have covered previously in class.

> So everyday, we have a warm up…the warm ups are pretty extensive, and I ask a lot of questions, they are extension questions from the original questions I ask, and the kids get pretty good at it. It is an adjustment, I don't expect perfection, it is ok if they get something wrong, which is pretty hard for them to get (James, interview, 10/27/14).

James described using his warm ups to get an idea of what students understood from prior lessons and then aimed to build on their understanding of this prior science content. Christy described her approach for pressing students to explain their understanding.

> Put it into your words and right away the kids want to grab the book and give me the definition, but I say no, tell me, I always play the role, I am 9 years old, I have no idea about chemistry and I ask you, what is this? And they give me whatever they wrote from the book and I say, but why? I act like that. Why, what do you mean? I force the kids to be the teachers. And another kid will add something else and by the end we discuss and talking and giving examples and teaching me. I do that a lot, I let them teach (Christy, interview, 10/6/14).

Table 3

Teachers' goals identified from their descriptions of their classroom instruction

***Theme*/Goal**	**Christy**	**James**	**Helen**	**Jody**	**Simon**	**Sharon**	**Joe**
Student thinking							
Assess students recall of science knowledge	X	X	X				
Have students explain their understanding of a scientific phenomena	X	X					
Elicit students initial ideas about science content			X	X	X		
Student responsibility							
Scaffold student autonomy, freedom, agency with knowledge	X	X		X		X	X
Scaffold student autonomy, freedom, agency with strategies			X			X	
Use peer collaboration to support student autonomy, freedom, agency	X	X		X		X	
Have students understand it is acceptable to make mistakes	X	X		X			X
Student participation							
Slow down instructional pace	X		X	X	X	X	X
Teacher designs/controls science practices			X	X			X
Student designs/controls science practices	X	X			X	X	X
Student relevance							
Use everyday situations to help students learn science content			X	X		X	
Depict how science applies to other situations					X	X	

Christy explained how she thought having students explain their thinking to her led them to a better understanding of the science content. In both of these cases, James and Christy described instructional strategies that encouraged students to share their thinking about science. While these strategies were useful for assessing students understanding of science, they do not fully embody the types of student talk and discourse within the NGSS.

In contrast, Helen, Simon, and Jody all described wanting to provide students with opportunities to discuss their initial understanding of a science topic before they taught the material. "I would like to do more at the beginning, before I start telling them anything. I am working on how to incorporate that" (Helen, interview, 10/8/14). Despite having students do projects and activities after she has taught course material, Helen expressed her interest in having students do more before she taught them the lesson.

Simon discussed that eliciting students' initial ideas might serve as a tool to help students reflect on what they had learned throughout a unit.

> Simon: You know, maybe a pre model and post model. The pre model could be a drawing, what does it look like, what do you know? And have them modify that model when they get through to the end.
> Jarod: Yeah, that is a lot of what the NGSS is, giving kids an opportunity to play a little bit, and then you understand where they are at.
> Simon: They get to see, this is what I knew on the first day, and here is what my model looks like on the last day (Simon, interview, 10/6/14).

Simon explained that eliciting students' initial ideas about science could be a tool for students to reflect on and revise their initial ideas. Jody discussed the possibility of having students diagram their initial ideas about the physiology of CPR.

> I am thinking I might do with them, because they going to do CPR…I want you to do a drawing of what you are doing. What is happening inside the body that is preventing them from dying? So, I am trying to think do I put some key words on

> the board, oxygen, carbon dioxide, we know blood, heart, brain, so using these terms, I want you to do a drawing of what you think is happening when you do CPR (Jody, interview, 10/8/14).

Jody described providing students with some key terms to include in their drawings, but tasked students with depicting their initial models about what they thought was going on inside the body during CPR.

Eliciting students' initial ideas about a science topic is an essential feature of some of the science and engineering practices in the NGSS. Having students develop and revise models of scientific phenomena, ask questions about their own interests in science, and construct their own explanations for scientific phenomena are all premised on teachers providing opportunities for students to share their initial ideas about science. This provides opportunities for students to build on and refine their initial ideas using new knowledge, empirical evidence, and repeated evaluation of them.

Student responsibility. The previous science education standards (*National Science Education Standards*, NRC, 1996) approached the teaching of the processes of science as separate from the teaching of the content of science. For example, the investigation and experimentation section of the previous standards came as a separate section immediately following all of the content standards. The NGSS views the processes of science and the content of science as intimately integrated and as a result the science and engineering practices were developed to depict the integration of them. The NGSS demands that students take responsibility for their own learning experiences, learning content through their participation in the science and engineering practices.

Teachers varied in the degree to which they described allowing students to be responsible for their learning through these practices. In some instances, teachers described strategies where they insisted on supporting student learning by *scaffolding student responsibility with learning strategies and/or background knowledge to support their learning*. In these instances, teachers viewed organizational strategies and background knowledge as prerequisites for participation in the science and engineering practices. In other instances, teachers described classroom instruction where students relied on *peer collaboration to figure out content on their own* and incorporated classroom norms that *promoted productive and inconsequential failure (i.e. acceptable to make mistakes).* These approaches viewed the science and engineering practices as integral to students learning science content. In this section, though, the contrasts are not as obvious as the previous section. Teachers' described classroom instruction seemed to hint at using the science and engineering practices to support students learn science content, but also described how they intervened with strategies and background knowledge to support student responsibility and participation in those practices. I highlight a few different examples to depict the variation in instructional strategies teachers described.

Some teachers expressed that it might be important for students to have some background knowledge before trying to figure out scientific ideas on their own.

> The best thing we have in models in chemistry is the atom, but we cannot give the kids, at least not that I think of, all of the background knowledge to get the same answers of different models of the atoms that they came up with. The problem is that kids already know the current model of the atom, so they aren't going to come up with previous models like the plum pudding model. But you can certainly help them understanding how those models changed and came to change (Joe, interview, 10/6/14).

In this case, Joe discussed having students understand previously revised models of the atom might help them better understand the current model of the atom.

James built on this approach and insisted that providing students with some background knowledge could support them in using that knowledge to take the next steps in solving scientific problems.

> But I'm not sure if any of us are sold on the idea of them discovering it for themselves. Some, like if you taught A, B, and C and they figure out D, as opposed to trying to figure out A, B, and C on their own (James, interview, 10/27/14).

James described wanting to equip students with enough content knowledge to be able to use that knowledge to figure out a scientific problem. In this example, James felt that students needed background knowledge in order participate in the science and engineering practices.

Another strategy for having students take responsibility for their learning experiences was to help students systematically organize their ideas for difficult questions and scientific problems. Helen discussed how she supported students in solving mathematical problems by helping them systematically organize problems.

> I want them to be comfortable with the math. They are working in groups so they can support each other. I walk through and read it with them. I ask them what information are they given and what are you trying to find. I tell them to attack every problem like that. Circle it, underline it, and then we start to go through, we do a problem (Helen, interview, 10/8/14).

Helen provided specific strategies (e.g., "what information they are given and what are you trying to find") for organizing a difficult mathematical problem in her science class.

Sharon discussed approaching student responsibility and participation in the science and engineering practices slightly different and scaffolded student responsibility by helping students systematically organize their ideas to difficult questions and scientific problems. She described an instructional activity where students were given properties of elements and asked to re-create the periodic table based on these properties. During this activity, Sharon discussed giving some hints about how to solve the scientific problem students were faced with.

> Sharon: I told them put the knowns, you have the periodic table, you have the knowns down and then figure out where the holes are and start placing them and they were like, this is hard. And you know, I was like yeah, well where should they go? Well, you're the one who has to figure that out. Think about Mendeleev, he didn't even have the periodic table to have those knowns.
> Jarod: Essentially, he had all these characteristics and features
> Sharon: And he had to figure it out just using characteristics. At least you have a head start (Sharon, interview, 10/15/14).

She mentioned that at times she needed to give them small hints about the content to support their investigations.

> I had to go around the room and give them hints. Oh, look that one is a gas, are the gases over here? No, no they are over here. So like trying to get them to do that…I was trying to get them to be able to look at the properties, investigate the properties and paste them on, where they belong, so part of it is, hoping that they will understand the periodic table better, learn to investigate and learn how to use that reasoning on these are all brittle and I have this one that is brittle, but I have nothing else that is brittle, so it must fit in (Sharon, interview, 10/15/14).

While Sharon insisted that students needed some organizational strategies to participate in this activity, she also mentioned that she hoped that having students try to build the periodic table using characteristics of the elements would help them better understand how the periodic table was organized. She utilized the investigation into the periodic table as a way to help students learn about its organization. Sharon's approach was different than the previous two in that she began with an instructional activity where students were tasked with solving a scientific problem on their own, but during the process supported their inquiry with some content knowledge pertinent to the task.

In another example, Jody discussed supporting students with strategies and knowledge but in a way that reflected her insistence on shifting responsibility to students.

> Now I guess, I have been teaching for a long time and we seem to swing really far back and forth. My gut tells me that we need to be somewhere in the middle. They still need instruction, still need an expert in the room…but whenever possible they should figure it out for themselves (Jody, interview, 10/8/14).

Jody's description of an expert assumed that someone with content knowledge might support students' efforts to figure out content on their own. She elaborated on this idea later in the interview, discussing an approach where students could take responsibility for helping each other learn.

> Jody: So having the kids put that [diagrams or drawings modeling a scientific phenomena] up, they are doing that so that I [teacher] can evaluate it, but there also, maybe I haven't taught it very well and another kids poster can strike a kid by looking at someone else's model.
>
> Jarod: Then they can go back and revise there's.
>
> Jody: Yeah, you aren't cheating, go back from what you've seen. You've looked at everyone else's, what now. So how would you revise it if you had 5 minutes, go and do something to it (Jody, interview, 10/8/14).

Jody's description of an activity where students drew models, looked at each other's models, and revised their own models based on what other students drew was a teaching approach where the students participated in the practice of modeling in order to learn about the physiology of CPR.

James used learning from peers differently than Jody in that he described using heterogeneous groupings to support students during instructional activities.

> James: When they are preparing the warm up, projects or labs, I'll have them work in groups of four. The high achieving kid and there is usually a kid who needs help
>
> Jarod: Heterogeneous groups?
>
> James: Yeah, definitely, it works out, I try to balance it out so that they group leader doesn't do all the work and just tutor, but in reality they do a lot of tutoring (James, interview, 10/27/14).

James shared that he purposely designed participation structures so that students could support each other during warm ups, projects, and labs.

Lastly, teachers discussed the importance of helping students understand that it was acceptable to make mistakes during their scientific investigations and inquiry and that making mistakes was part of the learning process in school and science.

> It is ok if they get something wrong, which is pretty hard for them to get. When I get kids their original idea is that they don't want to say anything unless I know I am right and then my system is if you don't say anything then you aren't trying and there is a consequence for it, but if you get it wrong, that is ok (James, interview, 10/27/14).

> Yes, it opens their minds. They are afraid to be wrong. That is something that I also need to work on. Give them the confidence that is how we use experimentation and science (Christy, interview, 10/6/14).

James and Christy insisted that students participated in class, not only so that they could hear students' thinking and responses, but also in order to promote student discourse and participation in the learning process. In another way, teachers explicitly communicated to students that making mistakes was part of the scientific discovery process.

> And sometimes, if they get it wrong, that is ok, when they hear others give their interpretation and it is their chance to talk and they say we got something totally different, and I say, that's how it is, experimentation (Christy, interview, 10/6/14).

> You could show them the experiments and ask them how might you and if they come up with a good way of interpret the data that is not right, it doesn't matter if it is a good interpretation of the data. That is a great idea (Joe, interview, 10/6/14).

In these cases, teachers communicated to students that making mistakes was part of exploring and interpreting experimental data. Having students understand that it was acceptable to make mistakes is consistent with the understanding that the nature of science is tentative and revisable. Supporting students in taking responsibility for their own learning experiences is another essential feature of the NGSS, yet teachers varied in the degree to which they allowed students to utilize the science and engineering practices to learn the science content being covered in class.

Student participation. The NGSS demands that students take responsibility and control over their participation in the science and engineering practices. In this study, though, teachers' descriptions of having students participate in the science and engineering practices varied in the degree to which teachers shifted the locus of control to students. In some instances, teachers experienced some difficulty in releasing control over student learning experiences and *largely controlled and designed instructional activities around the science and engineering practices for students*, whereas in other instances, teachers shifted the locus of control to students where they *[students] designed and controlled their participation in the science and engineering practices*. In these cases, teachers acknowledged trying to relinquish some control over how students participated in the science and engineering practices and provided opportunities for them to take responsibility for the design and/or control of them. To depict this contrast, I selected quotes from interview transcripts where teachers' described instructional strategies illustrated the varying degrees in which teachers shifted the locus of control to students.

In one example, James described guiding his students through research around the periodic table of elements, focusing their attention on the information that he felt was most important for them to learn.

> So, we are going over atoms in the periodic table, with atoms they are going to have play-doh I give them periodic tables and I assign each table group their own element, and they have to create a model atom of it…[then] they are going to do a group presentation…and explain the physical properties and where they are located and there are certain things that each group will present, but they can

> figure out how to put their poster together or some want to do a Powerpoint or a Prezi (James, interview, 10/27/14).

James's description illustrated how he structured students' research and participation in classroom activities.

Similarly, Christy and Simon discussed how they designed classroom activities where students built scientific models.

> For example, instead of talking about chemical reactions, putting on the board the chemical reaction, I give to the students paper clips with different colors and I have a reaction of water decomposition, I have water becomes hydrogen and oxygen. I will give the paper clips, different colors one for hydrogen and one for oxygen, and when the reaction happens, they can see that I have the same number of atoms, but there is no water anymore. They still have 2 hydrogen's, things like that. Definitely we are trying to use more representations (Christy, interview, 10/6/14).

> This is a model [teacher points to an animal cell construction kit they are doing in class now, students select different everyday materials, fusilli noodles, a string of beads, pieces of metal], I understand it to a degree that I can draw it… they ask where do they put this stuff, and I say that is up to them. You tell me which is best for Golgi apparatus, does this work for Golgi or does this work for Golgi, and why would you use this? They have the choice, then you tell me what they all do and so they as a group have to design it (Simon, interview, 106/14).

In both of these examples, Christy and Simon asked students to utilize provided materials to create a model that demonstrated their understanding of a specific scientific phenomenon. While students built scientific models, the teachers largely controlled the design of those models.

In contrast, some teachers discussed shifting the locus of control to students by making experiments more open-ended and asking students to design their own procedures for them. Christy and Sharon discussed a lab that they both used to challenge students to develop their own procedures.

I used one of the experiments that you did to us, the one with the bubbles.

> Bubbles everywhere. But I did my version, and said air everywhere, because we were talking about gas, and it is, the bubbles made air that is contracting and expanding, so I apply your experiments and my concept and was funny to see the students try to do it, try to make convex and concave, but I didn't give any instruction. Many students put the soap inside the bottle and mix it like this [turning hands up side down], and try to observe the bubbles, and they say there are so many of them, how are we supposed to see (Christy, interview, 10/6/14).

> Sharon: I have done a couple, three small labs, like mini labs.
> Jarod: Tell me about them.
> Sharon: One was a bubbles lab, where kids had three different solutions and they had to put soap into there, but I didn't give them the procedures (Sharon, interview, 10/15/14).

Allowing students to design their own procedures for labs was one way that teachers shifted the locus of control to students, tasking them with designing their own experimental procedures. In another example, Jody discussed having her students design a solution to a scientific problem in her sports medicine class.

> Normally I would go and demonstrate how to wrap a shoulder, they already know internal and external rotation, I would show them the position, give them the sheet, demonstrate and then have them go back and do it and come and look at each persons and then send them back. But instead of doing that I said ok, I want you guys, you know this is external rotation and this is internal rotation [demonstrating the movements with her own arms], I want you to prevent external rotation. You have this wrap and this piece of tape, you don't want them to do this [external rotation]…Go! You have tape and a wrap (Jody, interview, 10/8/14).

In this example, students were given autonomy to develop a solution to the posed problem and then presented their model to the teacher for feedback. She discussed the efficacy of having students design and control their participation in the activity later in her interview.

> And you know, it was so fun, so fun to watch, and they really came up with some creative things, some of them I said they would never be able to put their uniform on if they did that, but you did what I asked you to do. Others came up with a general shoulder splint. The thing that was so amazing was that they next time, I gave them some feedback, no look what you did, they were thinking about the direction of pull all these things that normally I am telling them and they don't get, and when we did the opposite activity, I said now, they seem to have a much

> greater understanding of that, but I wasn't 100% sure, but we did the opposite, I want you to prevent internal rotation, and 95% of the kids did it right the first time. They positioned them correctly. There was such a greater understanding of what they were trying to do versus me telling them how to do it (Jody, interview, 10/8/14).

In this instance, Jody expressed how allowing students to explore their own understanding of a model and then revising their model based off of new information and feedback was a really productive learning experience for her students.

The NGSS expects that students exercise autonomy in their participation in the science and engineering practices. Designing their own experiments, developing models of scientific phenomenon and asking scientific questions based on their own science interests are three of the science and engineering practices in the NGSS. Providing opportunities for students to control and design their participation in these practices is a major feature of the NGSS.

Student relevance. The NGSS expects that students notice everyday observable phenomenon as possibilities for scientific inquiry. While teachers did not discuss relevance in this manner, they often mentioned how they wanted to help students connect science to the "real world". I parsed teachers use of the term real-world into two different ways, teachers' goal to *use everyday situations to help students learn science content* (i.e. show students how the everyday experiences can be imported into the classroom to help students learn science content) and *depict how learning science might have everyday uses for students* (i.e. show students how learning science can be exported into the students' everyday lives outside of school).

One approach to using everyday situations to help students learn science content was by exposing them to novel experiences.

> I had the kids go outside and look at the mountains one day…it was Mount Wilson and this was in 8th grade we were starting to talk about astronomy…we went out they looked and we talked for five minutes, we walked back in and they settled down. Plus they saw mountains that they, wow, those are there? (Helen, interview, 10/8/14)

Helen shared that she wanted to point out that Mount Wilson was the highest point in the valley and was used as a satellite access point for most telecommunications in the area. By Helen taking her students outside to see Mount Wilson, she was trying to expose students to an everyday experience to support the science content they were learning.

Sharon discussed novelty in a different manner, where a novel experience in a lab engaged a struggling student.

> I remember the first year I worked here that was an F student…[and] I remember one day, I tried an inquiry lab, and I'll try it again this year, where they have to get oil out of water without taking too much water out. I remember hearing him say, oh my god, I like this, it is like real world stuff. So, I know it does tap into those kids, not all of them, but those kids, that aren't really, don't care about the regular classroom (Sharon, interview, 10/15/14).

Sharon suggested that the novel process of inquiry engaged this particular student and may have supported his participation in this activity.

Jody shared that everyday examples should be the premise for selecting what science content should be covered in class.

> We should be teaching about plants and animals, something they see in the real world. Maybe we'll actually add some more of this other stuff. They don't need to know the steps of mitosis. Who cares, but it is interesting, they need to know how sex cells are created versus body cells and that makes sense to me (Jody, interview, 10/8/14).

Designing classroom instruction around observable phenomenon might support students in understanding and applying science to out of school contexts.

In contrast, teachers described how science was useful for out-of-school contexts such as a future occupation or real life decision-making. Sharon and Simon described their efforts to get students to connect what they do in science class with what they might do in a job.

> Understand what they are going to be expected in the job market, because most jobs, some of them you'll go out and not have them [directions], their bosses will say just do this and find this (Sharon, interview, 10/15/14).

> That is all part of it. Maybe it is part of common core too, in the real world you have to work with people. Here is your group you have to produce this and if you don't work in the group, then your fired, or the group is fired. So that's real world stuff, and that is part of it (Simon, interview, 10/6/14).

Both teachers described how they wanted students to understand that the practices they learned in science class may be additionally beneficial for them in a future job. While teachers didn't discuss relevance in ways that aligned with the NGSS, finding ways to help students be more attentive to how everyday observable phenomenon can be gateways for scientific inquiry is an important feature of the NGSS.

Summary of interview findings. Across these interviews, teachers described a variety of instructional strategies around incorporating the science and engineering practices into their classroom instruction. In my analysis, it seemed that while teachers described a variety of strategies, they could be classified into a smaller set of goals that teachers pursued through their classroom instruction. The variation within and between each of these goals highlights some key findings from my analysis of interview transcripts.

First, it seemed that some of the instructional strategies that teachers used to pursue these goals looked similar to traditional notions of science teaching. For example, assessing student recall of science knowledge, teacher designing and controlling the processes of science, and scaffolding student agency with content were goals that many teachers pursued. Assessing students' recall of science knowledge seemed very similar to an initiate, respond, and evaluate (IRE, Mehan, 1979) discussion. Involving students in teacher designed and known answer labs resembled traditional "cookbook" labs where students followed explicit procedures for conducting an experiment. In addition, teachers' insistence on providing enough content knowledge so that students could participate in the science and engineering practices resembled notions of a separation between the science content and the processes of science from the previous science education standards.

In contrast, teachers also utilized instructional strategies that pursued some goals that reflected reform notions of science teaching. For example, teachers discussed incorporating opportunities to elicit students' initial ideas about a science phenomenon. There were also instances where teachers discussed giving students more control over their participation in the science and engineering practices. Teachers described these as new ways to give students opportunities to take more responsibility for their own learning experiences, yet this type of instruction was difficult for both students and teachers because they were very different than the type of instruction that both were accustomed to.

Varying Degrees of Alignment with the NGSS

In this section, I present the coherence between how teachers described their instruction around the science and engineering practices in the NGSS and my observations of what they actually did in their classrooms. I depict this coherence in terms of varying degrees of alignment with the NGSS. It is important to note that my notion of alignment is continuous and not discrete. There was variation within and between teachers, depending on the type of activity or specific practice being discussed or observed. For the purposes of this section, I use three categories of alignment to describe teachers' placement on this continuum, relative to teachers in this sample, high alignment, moderate alignment, and low alignment. High alignment depicts teachers whose described and observed classroom instruction aligned with each other and aligned with the goals of the NGSS. Moderate alignment depicts teachers where there was some misalignment between teachers' described and observed classroom instruction and/or with the goals of the NGSS. Low alignment depicts teachers whose described and observed classroom instruction did not align with the goals of the NGSS.

Immediately following each interview and classroom observation, I documented my initial thoughts about how teachers' ideas and instruction aligned with the NGSS in a running analytic memo. My overall sense was that all of the teachers in this study were interested and open to making changes to their teaching in order to meet the demands of the NGSS. Yet, in order to fairly depict teachers' degree of alignment, I decided on a few criteria. These decisions were made during data analysis. First, I examined the extent to which teachers were willing to make their lessons and activities more open-ended. This is a major feature in the NGSS and each of the science and engineering practices expects that students participate in open-ended activities rather than ones that are teacher controlled and designed. For example, a few teachers were not amenable to making their lessons more open-ended. One openly discussed his skepticism of the idea of having students figure content out on their own and designed instruction accordingly. By not subscribing to this idea of making lessons more open-ended I opted to place these teachers within the low alignment category.

The next criteria I used in determining teachers' degree of alignment was to examine the coherence between teachers' described classroom instruction and the classroom instruction I observed during classroom visits. For example, a teacher might describe his instruction as allowing students to investigate their own interests in science, but observations might reveal that students were allowed to choose a topic to investigate from a teacher designed list. In addition, I examined how teachers' described and observed classroom instruction aligned with the essential features of the science and engineering practices (see Appendix B). I used my understanding of the goals of the NGSS to determine whether there were any discrepancies between teachers' described and/or observed classroom instruction and the goals of the NGSS. This process allowed me to differentiate between high and moderate alignment. I placed teachers who showed any misalignment into the moderate alignment category. Teachers who showed little misalignment in any of the three categories mentioned previously, I placed within the high alignment category. Figure 1 illustrates my qualitative judgment of teachers' alignment. This figure depicts the degree of alignment between teachers' described and observed instruction with the NGSS.

In this section, I present case studies of each teacher that includes data from my interviews and classroom observations. I also include, when applicable, a description of my interactions with the teacher and the small role I played in supporting them in refining their lessons to incorporate the science and engineering practices. This typically involved providing some feedback—during the observation and/or virtually over email— to the teacher and seeing the ways he/she incorporated (or not) the feedback I provided to them. This section is organized by the three categories of alignment.

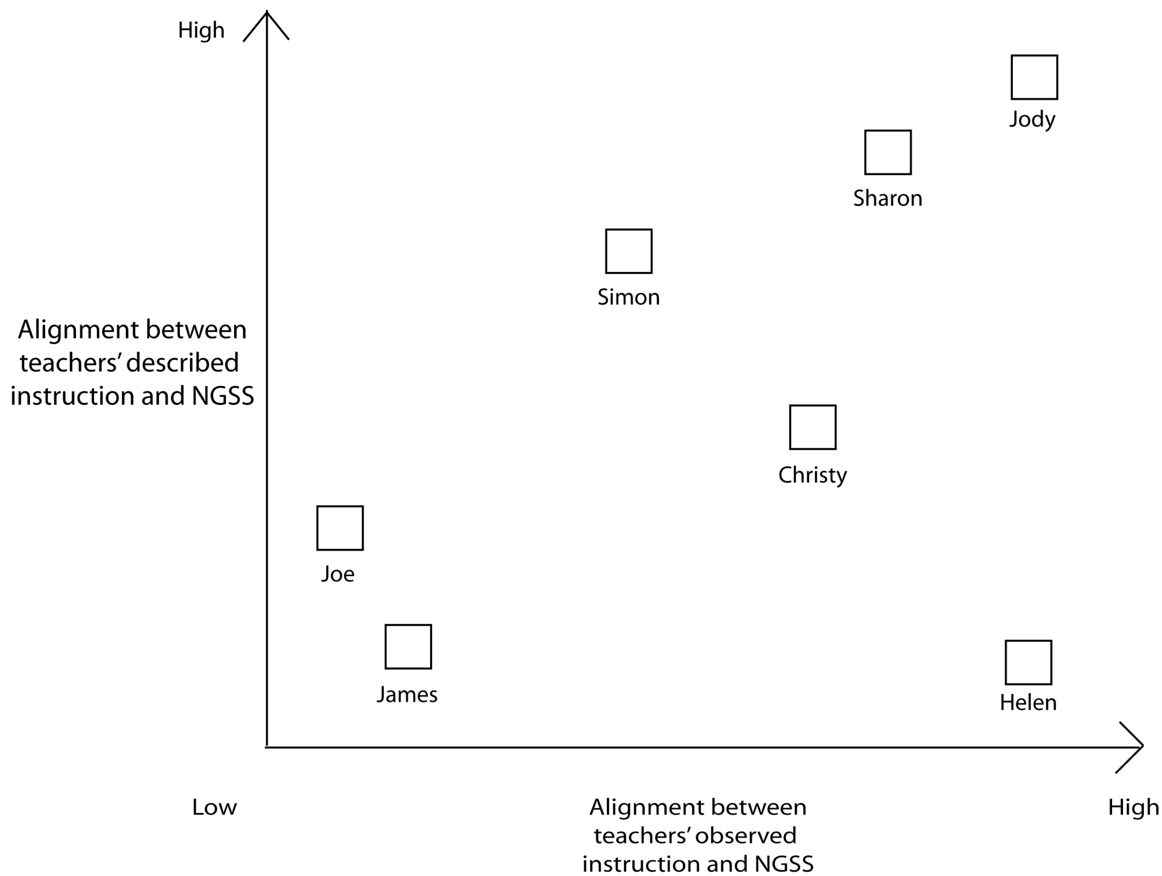

Figure 1: Qualitative judgment of teachers' alignment between their described and observed classroom instruction with the NGSS.

High alignment. In this section, I share two case studies—Jody and Sharon—that depict how their descriptions of their efforts to incorporate the science and engineering practices align with their classroom instruction around these practices and align with the goals of the NGSS.

Jody. I share two examples where Jody's described and observed classroom instruction align with each other and align with the science and engineering practices in the NGSS.

*Drawing and revising initial models of a scientific concept***.** In this example, I highlight Jody's described and observed classroom instruction around providing students with opportunities to share and revise their initial ideas about a science topic. Her described and observed instruction aligned closely with the *developing and using models* practice in the NGSS that includes features such as 1) models should be representations of a scientific phenomenon, 2) modeling is a repeated process of evaluation and revision, and 3) models must be based on empirical evidence. In my interview with Jody, I handed her a copy of the *developing and using models* practice in the NGSS. After reading the description she realized that the NGSS intended this practice to be conducted across multiple days where students had opportunities to revise their initial models.

> I guess the thing that I hadn't really thought about that is emphasized here is that their model is not a one day thing, that their model is changing over time, they are revising it, so that concept is like that formative assessment, it isn't wrong, you aren't being graded on it until you get it right, so what is wrong with this (Jody, interview, 10/8/14).

This discussion immediately conjured up Jody's recollection of an experience during the professional development workshop where she had the opportunity to participate in a group activity where her and her colleagues drew their understanding of a scientific phenomenon and then had the chance to view other groups drawings.

> Jody: Yeah, and the other thing that was powerful in our PD for me what I learned, the volume and temperature experiment. We made our posters and I drew it, because no one else wanted to, I didn't have a really strong idea of what was going on, I had a general idea, but when we went around and looked at the other posters, I learned a lot for the other posters. So having the kids put that up, they are doing that so that I can evaluate it, but there also, maybe I haven't taught it very well and another kid's poster can strike a kid by looking at someone else's model.
>
> Jarod: Then they can go back and revise theirs.
>
> Jody: Yeah, you aren't cheating, go back from what you've seen. You've looked at everyone else's, what now. So how would you revise it if you had 5 minutes? Go and do something to it.
>
> Jarod: Like you having the kids draw what is going on internally with CPR, it's called gallery walk, throw it up, take a look, take some ideas, what do you need to add or is yours perfect (Jody, interview, 10/8/14).

This conversation was important because during my first observation of Jody, she designed the class activity in a similar fashion to this description. During my first observation of Jody, students drew models of their initial ideas about how blood and air flow through the body during CPR, put their drawings up on the front white board for a gallery walk, and revised their initial models. At the beginning of class, Jody showed a news clip of someone that administered CPR for two hours and finally resuscitated the victim. She told students that the video was more for inspiration to show that first responders were highly skilled and trained to do their job. After the video, Jody explained the activity to the class.

> Ok, so I want to know what do you know now. This isn't graded and later you will be asked to modify it. Use your imagination and what you know from the past. You are going to draw a picture in pairs, about what you think is going on in the body during CPR. You have already done hands on CPR and watched a video about CPR. I want you to get creative. Don't stress out about this, just draw, what goes on in the body that makes CPR work (Field notes, 10/30/14).

Jody handed out large blank sheets of paper to students. She told them to think about how the person was lying on the ground and to draw from that perspective. Students worked with a partner and at times compared their drawings to others in the class.

Once students finished their drawings, students moved to the back of the room so that she could demonstrate CPR on a mannequin lying on the floor. After her demonstration, students assembled their mannequins (i.e. attach bags for the lungs, position mannequin on the floor) to practice administering CPR. Jody reminded students that their mannequin needed to be in proper form before they started. Jody showed another video that demonstrated proper form for CPR. After this video, students practiced on their mannequins. Jody asked students to shout out the number of compressions as they performed CPR on their mannequins.

Once every student had a chance to practice, Jody gathered students back to their desks and asked students to tell her about the key structures and ideas related to what happens inside the body. Students responded with key structures within the body involved in CPR (e.g., blood, oxygen, lungs, capillaries, sternum). A student wrote down the responses on the white board. Jody told students that they would now create their second model, incorporating the terms from the brainstorm. She encouraged students to share ideas with other students, utilize their first models, and see what they could add or change in their original model based on the additional information they gathered during class. Students drew their second models with the same partner. After students finished their second model, Jody gave them tape to put their models up on the front white board. She asked students to get up and walk past each of the models and think about how they might incorporate ideas from someone else's drawing. During the gallery walk, Jody told students that they would be doing a final model later in the week.

Jody designed instruction so that students would take responsibility for figuring out the content on their own. During this class period, she had students work collaboratively to draw their initial models and then encouraged students to compare their models with other groups during the gallery walk. Having students work together and share ideas supported their efforts to figure the content out on their own. She also wanted students to understand that it was acceptable to make mistakes and that they would be given opportunities to revise their models.

In addition, Jody elicited students' initial ideas about the physiology behind CPR by having students draw initial models with little instructional support. She pursued her goal of getting students involved in the science practices by having students revise their initial models based on additional information they gathered throughout the class period. This type of activity was new for Jody and she discussed how difficult it was to allow her students to make mistakes. Later that week, I asked her about students' final models.

> Jarod: Did students get a chance to finish their final models?
> Jody: We ran out of time to do it in class, but they are working on them when we have extra time in class.
> Jarod: So, how do you think it went, as far as them learning the content?
> Jody: They did great. I think they learned the material quicker and more accurately and not only that they seemed to really enjoy it better and were excited to learn the material (Field notes, 11/14/14).

Jody's openness to feedback on how to modify her lessons and willingness to allow students to take responsibility for their own learning experiences proved to be useful and productive for her students in learning the science content covered in her class.

This example highlighted how Jody was able to articulate her goal of having students share and revise their initial ideas about a science phenomenon that was in alignment with the *developing and using models* practice in the NGSS. This alignment allowed her to design instruction around students' initial ideas about the physiology of CPR to pursue that goal. Our discussion around the *developing and using models* practice made the essential features more explicit (e.g., revising initial models), and provided Jody with an understanding of the practice so that she could enact it in her classroom teaching.

Solving a scientific problem with little instruction from teacher. In this example, Jody discussed giving some control back to students by having them figure out a solution to a scientific problem with little prior instruction. Jody described and enacted this instructional activity to pursue this goal. It is important to note that Jody teaches a sports medicine class to 11th and 12th graders.

In my interview with Jody, she discussed using an approach where students were given autonomy to develop their own solution to a sports related injury using their science knowledge about muscle movement in the shoulder.

> Normally I would go and demonstrate how to wrap a shoulder, they already know internal and external rotation, I would show them the position, give them the sheet, demonstrate and then have them go back and do it and come and look at each persons and then send them back. But instead of doing that I said ok, I want you guys, you know this is external rotation and this is internal rotation [demonstrating the movements with her own arms], I want you to prevent external rotation. You have this wrap and this piece of tape, you don't want them to do this [external rotation]…Go! You have tape and a wrap (Jody, interview, 10/8/14).

In this example, students were given autonomy to design their own solution to a scientific problem and then present their solution to the teacher. Jody then had the opportunity to provide feedback to students on their solution and re-orient them towards the learning objective. Jody discussed this point during her interview.

> And you know, it was so fun, so fun to watch, and they really came up with some creative things, some of them I said they would never be able to put their uniform on if they did that, but you did what I asked you to do. Others came up with a general shoulder splint. The thing that was so amazing was that they next time, I gave them some feedback, no look what you did, they were thinking about the direction of pull all these things that normally I am telling them and they don't get, and when we did the opposite activity, I said now, they seem to have a much greater understanding of that, but I wasn't 100% sure, but we did the opposite, I want you to prevent internal rotation, and 95% of the kids did it right the first time. They positioned them correctly. There was such a greater understanding of what they were trying to do versus me telling them how to do it (Jody, interview, 10/8/14).

Jody's goal was to have students utilize their own understanding of the physiology of how the shoulder moved to figure out a solution for preventing a particular movement. During my second observation of Jody, she used this approach to have students perform a hip wrap without her demonstrating it first, only using their prior knowledge of how the hip moves. Jody said that the students had success with the shoulder, so she wanted to see if they could have the same success with the hip.

Jody told the students that their materials included wrap and plastic heel lift. Students were asked to wrap their partners' hip and show Jody so that she could check their work. During the process Jody announced to the class that she was going to ask them a few questions about their wrap. "I am not saying you are wrong, but I just want to know about your thinking" (Field notes, 1/20/15). Jody encouraged students to use academic language. For example, a typical question that she asked students was which way did they pull the wrap when securing the leg. One student responded "medial to lateral" (Field notes, 1/20/15). Jody praised this student for using appropriate academic language and used the same language when checking other students' work. She also asked questions such as what is it called when the hip pulls out (abduction)?

Once she checked all the students' wraps, she gathered the students back to the desks to watch a video that demonstrated the proper way to prevent hip abduction. She quickly reviewed the content in the video.

> Jody: So you pull in the direction you are trying to prevent. Why loosen up [the wrap] in the back?
> Student 1: So it won't hurt when they play
> Jody: Why up over the Gluteus Maximus?
> Student 2: So that it won't slip.
> Jody: Positioning the student is really important (Field notes, 1/20/15).

After the video and short discussion, Jody had students perform their hip wrap again, encouraging them to follow the procedure discussed in the video. Students again had their work checked by Jody. She utilized the time to praise students work and correct any mistakes they had made. Once all the students showed their wraps to Jody, she reviewed the process with the entire class once more, reminding them of the appropriate language to use when describing their wrap.

In this example, Jody pursued a goal of having students figure out content on their own and by designing instruction around a scientific problem (i.e. preventing hip abduction) for students to solve (i.e. wrapping partners leg) with little instruction. By not demonstrating the exact procedures, she pressed students to take responsibility for their own learning experiences. This example highlighted how Jody understood the goal of having students take more responsibility for their learning experiences that allowed her to design appropriate instruction around this goal. In this case, Jody was able to understand her goal in way that made its enactment feasible in her classroom.

Sharon. In this section, I share an example that includes data from Sharon's interview and two observations of her classroom teaching. The purpose of discussing both observations is to highlight Sharon's effort to refine her classroom instruction around the science and engineering practices, incorporating feedback I provided to her into her classroom teaching. It is her evolving understanding of how to promote student discourse in her classroom, especially in a short amount of time that suggested to me that she be placed in the high alignment category.

In her interview, Sharon described instruction that pursued the goal of having students take responsibility for their own learning experiences. She described instructional activities where students were pressed to figure out content on their own with little prior instruction. During my observations of Sharon, she pursued this goal by designing classroom instruction to provide opportunities for students to participate in class activities with little prior instruction and pressed students to explain their understanding of the science content they covered in class. The following case study illustrates the alignment between her described and observed instruction and also includes my interaction with Sharon to support her in refining her classroom instruction to make students' ideas and explanations more explicit during class.

During Sharon's interview, she discussed a few different instructional activities that she had incorporated into her classroom teaching. In one particular activity, Sharon described tasking students with solving a scientific problem with little prior instruction. In this activity students were given properties of elements and asked to create the periodic table based on these properties.

> Like over there the Mendeleev lab, it is an inquiry thing where they are given properties of elements and then they have the notes so they can go ahead and place the notes on the periodic table, but they have spots where they don't know. So I was trying to get them to be able to look at the properties, investigate the properties and paste them on, where they belong, so part of it is, hoping that they will understand the periodic table better, learn to investigate and learn how to use that reasoning on these are all brittle and I have this one that is brittle, but I have nothing else that is brittle, so it must fit in (Sharon, interview, 10/15/14).

During this activity, Sharon described pressing students to think through and apply their knowledge of how the periodic table was organized in order to reconstruct it based on the physical properties of the elements.

Sharon:	I told them put the knowns, you have the periodic table, you have the knowns down and then figure out where the holes are and start placing them and they were like, this is hard. And you know, I was like yeah, well where should they go? Well, you're the one who has to figure that out. Think about Mendeleev, he didn't even have the periodic table to have those knowns.
Jarod:	Essentially, he had all these characteristics and features
Sharon:	And he had to figure it out just using characteristics. At least you have a head start (Sharon, interview, 10/15/14).

Sharon's described instruction pursued a goal of having students take responsibility for their learning experiences. In my observations of Sharon, her classroom instruction pursued this goal as well.

Investigating a guiding question. During my first observation of Sharon, she designed a series of activities for students to think about color and light waves. She assembled students into groups of three and introduced a guiding question "If all of us were to leave this room, would there still be color? Would there still be red, green, yellow, pink in the objects in this room? Explain your reasoning" (Field notes, 10/28/14). After seven minutes—using a digital timer projected onto the screen—she polled the class about their response to the question. Nine students indicated that there would still be color, 16 indicated that there would not be color, and one student indicated that he did not know. A brief discussion followed as Sharon asked students to justify their vote. When no one volunteered, she called on a few students to share.

> Student 1: Yes, even though a blind person cannot see, color still exists.
> Student 2: No, cones and rods [in the eye] cannot pick up color in a blind person.
> Student 3: No one is there to see the object, but still [there is] light and reflection off of objects (Field notes, 10/28/14).

Next, Sharon showed a short video about wave frequency and how people saw color. The video hinted that color was only a manifestation processed in the brain of people. She polled the class again about the guiding question. Three students indicated that there was still color if no one was in the room, 11 students indicated no, and six students indicated that they did not know.

> Student 1: So the answer is no?
> Sharon: According to the video the answer is no (Field notes, 10/28/14).

After the video, Sharon introduced the next activity where students used pliers to crush wintergreen candy. Within the candy was a material that, under pressure, reacted with gases in the atmosphere to create a green flash when its bonds were broken. The pliers were used to crush the candy and students observed the green flash. She told students that they needed to explain what was happening using the information they talked about and the information they gathered during their experiment. She gave them a hint saying that they should think about their previous discussion about Bohr's model of the atom when doing the experiment and writing their explanation. After students completed the short activity, they were asked to come up with an explanation for what was causing the green flash. In the small groups, students discussed plausible explanations for the green flash such as "losing electrons" and "having to with pressure" (Field notes, 10/28/14). The class period was running short so the teacher told students that the green flash had to do with "electrons jumping from one place to another as the sugar gets crushed. The electrons are moving from one orbital to another, you crush the sugar to release ultraviolet light and the wintergreen absorbs it and transforms it to florescent light" (Field notes, 10/28/14). After this explanation, the teacher asked students to submit their written papers before the bell rang.

Through this lesson, Sharon elicited students' ideas about a particular science problem by having them investigate color and light through their understanding of the atomic model. She framed the activity around having students provide responses to the guiding question and explain their reasoning in their response. This provided an initial opportunity for students to share their ideas during a whole class discussion and then another opportunity for students to revise and write their final explanations. She pursued her goal of having students take responsibility for their learning experiences by having students share their initial ideas and then work collaboratively to revise and develop an explanation for the phenomenon they observed in the lab.

Shortly after my observation of this class period, I sent Sharon an email with some ideas of how she might refine this type of activity, especially around eliciting students ideas and pressing them to explain their understanding of the science content.

> After reading through my notes, I had the thought that I wonder if you might have students revise their original ideas and re-share it with the group. You could have students try to persuade each other of their opinion as a way to have them argue/use evidence to support their claims. This is just slightly different twist on what you had them do, but it gets them re-thinking about their ideas after each time you provide them with a little more information about the topic. Just a thought since it sounded like you were planning to do more of these types of activities with your students (email correspondence, 11/14/14).

The intent of this feedback was to get Sharon to consider providing multiple opportunities for students to share during class, feedback that she incorporated into the next class I observed.

Developing and revising explanations. During my second observation of Sharon, she designed a lesson where students investigated the relationship between pressure and temperature through two short labs, a video, and a whole class discussion. Sharon indicated that the day before, the class started to go over the relationship between pressure and temperature. During this class period, students participated in two labs that illustrated this relationship and developed an explanation for the phenomena they observed in the labs.

The first lab had students investigate how temperature affected the movement of gas molecules. Students dipped the top of an empty water bottle into liquid detergent and then submerged the bottom of the water bottle into a beaker filled with hot water to observe how a bubble formed at the top of the bottle. As the gas molecules in the bottle heated up they created greater internal pressure pushing the gas molecules outward creating a bubble that formed on the outside of the bottle. They repeated the procedure; only this time they submerged the bottom of the bottle into a beaker filled with ice water and observed the bubble that formed at the top of the bottle. As the gas molecules in the bottle cooled down the gas molecules constricted creating a bubble on the inside of the bottle. In the second experiment, students used a pie tin filled with water and a candle in the middle of the pie tin. Students lit the candle and placed a beaker over the candle. The candle heated up the gas molecules trapped under the beaker, increasing the pressure and causing the water to move out from under the beaker to an area of lower pressure. Once the candle went out, the air molecules started to cool, decreasing the pressure, and causing the water to move into the beaker from an area of higher pressure to lower pressure. Students were given 15 minutes to write down their observations and explanations as well as diagram the phenomenon they observed.

After providing some initial directions for the labs, Sharon instructed students to assemble into their lab groups and follow the procedures on the lab desks. After 15 minutes she asked them to switch lab stations in order to complete the second lab. As students worked on the first lab, Sharon circulated through the room to support students with the lab procedures and press students to come up with an initial explanation for the observed phenomenon. For example, one student asked her why they are trying to guess this now if they likely won't get the right answer now. She responded with "in the real world, people do experiments without knowing the right answer. They try and figure it out. You'll get to revise your answer, right now I just want you to make a guess at what you think is happening" (Field notes, 12/5/14). After 15 minutes, she reminded students that they were responsible for completing the questions on the worksheet and told them to begin the second experiment. One group told Sharon their explanation. "The pressure increased in the cold solution and pulled the bubble down, where as the hot solution, the pressure pushed the air out and pushed the bubble out of the bottle" (Field notes, 12/5/14). She didn't respond, just nodded her head and said, "interesting" (Field notes, 12/5/14). The class finished the second lab and Sharon directed students back to their seats to show them a video that discussed the relationship between pressure and temperature, in terms of kinetic and potential energy in car tire pressure on cold and warm days. She stopped the video midstream to check students understanding of the content in the video.

Sharon:	We talked about kinetic energy. What is happening [when molecules get cold]?
Student 1:	It [kinetic energy] is leaving.
Student 2:	It turns into potential energy.
Student 3:	No, it starts to decrease.
Sharon:	Right, the kinetic energy goes down. When it gets colder the kinetic energy slows down and begins to decrease (Field notes, 12/5/14).

Sharon resumed the video and at the conclusion of the video she asked the class a few questions.

Sharon:	What are the three things that matter for tire pressure?
Students:	(a few in unison) Temperature, volume, and pressure
Sharon:	So on a warm day, what happens to kinetic energy? It increases and what happens to pressure is that it increases too. And what happens to the volume, it increases so that is on a warm day. What about kinetic energy on a cold day? Pressure, volume and temperature decrease. Now go take that new knowledge and go back and revise your [explanations] on the two activities. You have 10 minutes to talk with your group and turn in your papers (Field notes, 12/5/14).

Sharon circulated the room again to check in on groups. She had the conversation below with one of the groups.

> Student 1: So when it is hotter, the pressure expands, so they [temperature and pressure] are the same then, right?
>
> Sharon: Yeah, so think about temperature, pressure, volume, and draw a revised picture of what you think is happening. You should include the additional information you heard in the video, ideas about temperature, pressure, and volume (Field notes, 12/5/14).

Students finished their papers in their groups and submitted their papers right before the bell rang. I had a conversation with her right before the class ended. I mentioned that I heard her say a few times to students that they needed to explain why they thought it happened rather than just write down what happened. She said that her students really struggled with this. She pressed them, but she said they got very frustrated because they typically didn't have to fully explain themselves. They always did just enough to get by. They would finish their work to get credit, but she really wanted them to push themselves to really understand why something happened. She stated that she plans to do this type of activity a few more times this year. She hoped that would get better at it, but as of now, they really struggled.

During this class activity, Sharon pressed students to take responsibility for their own learning experiences by not giving them the answers after the lab and helping them understand that it was acceptable that their initial ideas might be incorrect. She emphasized that students needed to explain their understanding of the phenomenon they observed during the two labs. In the second observation, she attempted to incorporate a strategy I suggested, asking students to write down their initial explanations after completing both labs and then revising their initial explanations after watching and discussing the video. She designed the student worksheet so that they were forced to revise their initial explanations after watching the video. While she didn't have them share their revised ideas with the group, she had them work together to write up their revised explanation. Sharon's goal of having students explain their ideas and pressing them to take responsibility for their own learning experiences manifested itself in the design of her activities that provided students with opportunities to revise their explanations based on additional information she provided to them. Eliciting students' initial ideas and having them revise their explanations aligns closely with the goals of the science and engineering practices in the NGSS.

In this example, Sharon showed a developing understanding of the science and engineering practices, especially around helping students refine their own ideas about science. Her understanding of having students take responsibility for their learning experiences developed across my first two observations where Sharon refined her approach to having students think about, share, and revise their ideas about a scientific phenomenon. Coherence between her described and observed classroom instruction made it feasible for her to receive feedback and incorporate a strategy that supported her goal.

Moderate Alignment. In this section, I share three case studies—Helen, Simon, and Christy—where there is either misalignment between teachers' descriptions of their efforts to incorporate the science and engineering practices and their classroom instruction around these practices or misalignment between teachers' described and/or observed classroom instruction and with the goals of the NGSS. For Simon, he described classroom instruction that aligned with the goals of the NGSS, but my observations of his classroom instruction didn't seem to match his descriptions and included some traditional ideas about science teaching. For Christy, her described classroom instruction matched my observations of her classroom teaching, but they were in misalignment with the goals of the NGSS. For Helen, she struggled to articulate how she was incorporating the science and engineering practices, yet my observations of her classroom teaching revealed instructional approaches that aligned with the goals of the NGSS. In this category, the teachers' misalignments were very different from one another, yet this depicts how teachers widely varied in their understanding and enactment of the science and engineering practices.

Simon. In this example, I illustrate the misalignment between Simon's described and observed classroom instruction. In the interview, Simon mentioned that he was focused on getting better at incorporating the *developing and using models* practice into his classroom teaching. During my observation of Simon, he designed a class activity where students modeled a scientific process, though, in a way that was different than his description of the practice.

During his interview, Simon discussed his understanding of modeling and how it could be incorporated into his classroom instruction. He described a classroom activity where students used a set of materials and their understanding of a scientific topic to build a scientific model.

Simon: The other thing is models, modeling is a great thing. Most of us aren't doing that as much as we want to, so that is one thing we identified

Jarod: Tell me a bit more about what you mean by modeling?

Simon: Being able to synthesize the concept in my head and putting it together in a drawing or in a sense this [points to a cell construction kit they are doing in class now, students select different everyday materials, fusilli noodles, a string of beads] is a model, I understand it to a degree that I can draw it. It demands a certain type of cognitive synthesis that I have the concept and I am not just regurgitating it, I get it. It involves sitting down, this [cell model project] is in groups, could be describing how a ribosome is built, how a protein, they can write that out or give me a picture, or somebody else was describing in our meeting a cell city, here is a city, draw a city and now apply the organelles of the cell to that city. Where would the ribosome be in that city? That is a model approach we are thinking, we are using, maybe I don't have it all (Simon, interview, 10/6/14).

Simon described his understanding of modeling as having students represent and explain a scientific phenomenon. He described an example of having students use everyday materials to represent cellular structures. Later in the interview, he elaborated on this understanding, describing how he might use models as a resource to access students' initial and final ideas about a science topic in order to have them reflect on what they have learned throughout a unit.

> Simon: It [modeling] is one thing we have identified as a department as one thing we want to get better at…You know, maybe a pre model and post model. The pre model could be a drawing, what does it look like, what do you know. And have them modify that model when they get through to the end.
>
> Jarod: Yeah, that is a lot of what the NGSS is, giving kids an opportunity to play a little bit, and then you understand where they are at.
>
> Simon: They get to see, this is what I knew on the first day, and here is what my model looks like on the last day (Simon, interview, 10/6/14).

Simon described instruction that pursued the goal of eliciting students' initial ideas about science as a tool for students to build on and revise their initial ideas. Simon continued this discussion and mentioned a tension between incorporating the science and engineering practices and still being held accountable for student learning.

> Simon: They get to see, this is what I knew on the first day, and here is what my model looks like on the last day. So, I don't know, it is a change. I think the tension is there for everybody. What is the test going to look like? It isn't all bad. It keeps us on track. I came from 30 years ago, where I could teach what ever I wanted, say bugs, because that is my thing. But they didn't, so there is a pendulum, where we were too much into the test and with common core.
>
> Jarod: So those are the areas as a group.

Simon: Most of us agree that the higher-level thinking is good. More so than just rote memory, regurgitated, here are all the organelles, I've got all my vocabulary on the board, I passed the quiz. I have no idea we need to get past that, we need that to get to the next step, but that is the transition that is going to be difficult and how do we fit that into 180 days and how do we cover all the content. We have a lot of content. I had a hard time covering the content before. There is a ton of content. We have meetings about what content can we cut out (Simon, interview, 10/6/14).

In Simon's case, it was plausible that this tension might have disrupted his efforts to design instruction around modeling in the way he described in his interview. During one of my observations of Simon, discussed next, he had students build models depicting three scientific processes—DNA replication, Transcription, and Translation—yet the purpose the models served was to assess students' understanding of the processes rather than a way to have students learn the processes.

Modeling DNA replication, transcription, and translation. In my third observation of Simon, students were tasked with using provided materials to model the three processes from the central dogma of molecular biology, DNA replication, Transcription, and Translation. Simon provided students with clothespins, two wooden sticks, and tape. The clothespins had the five nucleic acids—adenine, thymine, cytosine, guanine, and uracil—written on them and the wooden sticks intended to mimic the phosphate and sugar backbone for DNA and RNA. Simon told me that he previously used this activity as a review leading up to his unit exam, but he modified it to be a performance task to see if students could model the processes to demonstrate their understanding of them. Previously, he provided step-by-step instructions on how to use the materials to build models of the three processes. During this lesson, he stripped the directions down and only included the task—model the DNA replication, Transcription, and Translation—

activity directions—show teacher each process when it is completed to get credit for it—and some of the essential features that should be described when discussing their model with the teacher (e.g., role of messenger and transfer RNA, corresponding amino acids for the RNA chain). After the all the groups finished, Simon had a brief whole class discussion with students.

Students immediately got started on the first task, DNA replication. After 10 minutes, one group finished and discussed their model with Simon.

> Simon: Tell me what goes along the side of the DNA
> Student 1: Um mRNA?
> Simon: No, what else besides the nucleotides are in DNA?
> Student 1: *(no answer)*
> Simon: Sugar and phosphate groups make up the sides of he DNA strand (Field notes, 2/24/15).

Other groups also struggled with the first task. One group used a single wooden stick and had clothes pins attached to both sides of the stick and another group used uracil in their models of DNA. Simon circulated through the room talking to each of the groups correcting students' mistakes and helping them revise their models of DNA replication. After students struggled with DNA replication, they seemed to better understand what was being asked of them and quickly moved through Transcription and Translation. All but one group had finished modeling and explaining all three processes after about 20 minutes. For the groups that were finished, Simon handed them an article titled "Who owns genes?" The article was about the Human Genome Project and the increased number of private patents on genes. Students were asked to read the article and answer the discussion questions posed at the end of the article. Simon spent the remaining time with the struggling group, modeling Transcription and Translation with the students. Once this group was finished, Simon had a brief whole class discussion with students.

Simon: This activity is about making a scientific model. Taking a mental concept and putting it into another form to help convey that idea. Models can be equations or pictures. This time we used clothespins and wooden sticks to model DNA replication, Transcription, and Translation. I wanted you to use these materials to show me that you can take an idea and put it into another form to show me that you understand it. So, what part of what we did today involved a gene?
Student 1: Transcription
Simon: Because transcription is the process of making a…
Student 2: Protein
Simon: DNA is in the form of a code to make proteins and we are made of proteins (Field notes, 2/24/15).

Students read the article for the remaining time in the class period.

In this class period, Simon utilized models as a form of assessment, measuring students understanding of these scientific processes and using them as an opportunity to re-teach students about the science content behind the model. In his interview he described using modeling as a tool for student learning, whereas in his classroom instruction, modeling was used as a tool for assessing students' knowledge. The contrast between how Simon described modeling and how he enacted it in his classroom highlights the tension he described in his interview between incorporating the science and engineering practices, yet still being held accountable for students proficiency in science content. Simon was navigating the tension between understanding the goal of the *developing and using models* practice (e.g., using modeling as a tool for learning) and actually enacting that practice in his classroom. Reasonably, it was easier for Simon to talk about the practices than it was to enact them in his teaching.

Christy. For Christy, I describe an example where there is alignment between her described and observed classroom instruction but is misaligned with the goals of the NGSS.

Developing and using models. During my interview, Christy reviewed the description of the *developing and using models* practice in the NGSS and discussed her ideas about having students develop their own models.

Christy: Here it talks about developing models. I don't know if my students are there to develop their own models. So, I believe maybe for AP chemistry, I can expect that, they can develop their own model, but instead, I give you a model and you break apart how that model works.

Jarod: That is what you would like your students to do.

Christy: It is what I am already doing. I present models and analyze how it works, what do you think?

Jarod: So, dissect it break it apart, use it and explain.

Christy: Yes, and maybe after seeing different models and how they work, you can develop your own model. Because you have to have a base [of science knowledge] of creating, you have to have an idea of where this is coming from, these kids, they don't have the experiences, I've noticed that. Sometimes, I am talking about the atom, years ago I expected that they would know everything, but like I would be talking about the electrons and they still think it is in the nucleus. That is why I present the models and they dissect it. But here they are saying that you have to develop models… I mean I hope in the future they can (Christy, interview, 10/6/14).

Christy discussed her understanding of this practice in a way that was misaligned with the description of that practice in the NGSS. Rather than developing and using models, she understood this practice as dissecting and explaining scientific models. She stated that students needed to have some background knowledge before developing their own models. This hinted at a separation between the science content and science practices, an idea that is contrary to the view in the NGSS that explicitly states a perspective where the science content and science practices are integrated. In my observations of Christy, she had students participate in a modeling activity where she asked students to model chemical reactions using colored paper clips with little prior instruction, though during the activity, she often provided students with background knowledge that would help them create the correct chemical reaction model.

During my second observation of Christy, she designed an activity where students were asked to use paper clips to model a series of chemical equations listed on the white board at the front of the classroom. Students assembled together the paper clips to model the reactants of the equation and then were asked to demonstrate to the teacher how the paper clips rearranged themselves as the products in the chemical reaction. Christy provided the materials for activity—different colored paper clips—but did not provide any instruction on how to complete the activity. She encouraged students to work together to figure out how to complete the activity. At the beginning of class, I had a quick conversation with Christy about the class activities.

Jarod:	You didn't give them any directions.
Christy:	No, I want them to try and figure it out for themselves. I've done this with my AP class, but not with them. They make mistakes, but that is ok. That is the point. I want them to try and figure it out themselves, even if they make mistakes.
Jarod:	Have you done this before?
Christy:	Not this exactly, but they have tried to do a lab on their own. They produce an entire report from title to conclusions (Field notes, 1/23/15).

Students were given 20 minutes to complete the activity. Christy circulated the room helping students with their chemical reaction models. One group called her over to check their first reaction, the composition equation for water.

Christy:	You have one molecule of H_2 and one molecule of O_2. Can you combine them to make water?
Student 1:	Yes but we still have one O left over?
Christy:	What can you do then? Think about the molecules.
Student 2:	We need another molecule of H_2.
Christy:	Yes! Now how many molecules of water do you have?
Student 2:	Two.
Christy:	Yes, so what is the balanced equation look like?
Student 1:	Oh, 2 molecules of H_2 with 1 O_2 make two waters. Is that it?

Christy: Yes
Student 2: So you wanted us to balance the equation?
Christy: Yes! (Field notes, 1/23/15).

While this group was able to figure out how to model the reaction, other groups struggled with figuring out exactly what Christy wanted them to show her. For example, another group created both the reactants and the products with their paper clips, whereas Christy wanted them to only create the reactants and demonstrate to her how to rearrange the paper clips to create the products. Another group worked on a combustion reaction where methane reacts with oxygen to produce carbon dioxide and water. Christy went over to check on their work and they created their paper clip model of the chemical structure of methane incorrectly (i.e. connecting the hydrogens together instead of connecting each hydrogen to the carbon molecule). Christy reminded the class that they needed to create the correct chemical structure for each compound using the paper clips. Christy intervened during a few instances to give students hints about the science content (e.g., chemical structures of compounds) to help them finish the activity.

Providing students with enough background knowledge to participate in the science practices was a view that Christy expressed during her interview and it manifested in her classroom instruction. While providing students with little prior instruction to complete a modeling activity was aligned with the goal of having students figure out content on their own, making sure that students had enough background knowledge to develop their models hinted at the notion of a separation between science content and the science practices. The NGSS explicit states that the standards hold the view that science content and processes of science are intimately connected and integrated. Christy did not view participating in the science practices as intimately connected to supporting students in learning science content.

Helen. For Helen, she had difficulty describing how she had incorporated the science and engineering practices, yet in my observations of her classroom instruction, she effectively designed instruction that pursued the goals of the NGSS. In this example, I present a few excerpts that illustrate how Helen struggled to articulate examples of how she was incorporating the science and engineering practices into her classroom instruction and also present two examples of Helen's classroom teaching where she incorporated classroom activities that aligned with the NGSS. This misalignment between her described and observed classroom instruction suggests she struggles with understanding the explicit goals of the science and engineering practices but at the same time is probably already using instructional activities that aligned with the NGSS.

At the beginning of the interview, I asked Helen about new activities she was using in her classroom teaching in relation to the science and engineering practices. She discussed a classroom activity involving mathematical calculations.

> [Teacher hands me a paper with a series of calculations that kids did figuring out how long it takes light to get to each of the planets.] I walk them through the calculations, it goes from talks about measurement, developing different systems, instead of 93 million miles we have 1 AU…I tell them that we were talking about the sun takes 8 minutes. I told them there were ways to calculate it. At first they were like is this math or science…I do an example, the one with the inverse square law, we did do one of the examples like Jupiter, I did the asteroid belt, I made it easy. Once they realized that *d* was the distance, even though I told them, they said, oh, yeah, we got it (Helen, interview, 10/8/14).

I was unsure if my question was unclear to her, so I followed up with a question more specific to how she had incorporated the science practices in the NGSS.

> Jarod: Tell me a little bit, how have you thought about it, incorporate some of the practices from the NGSS. Have you tried it, thought

about it?

Helen: One of the things I want to try is get away from the traditional labs and go more towards inquiry. I kind of know what it is and I kind of know what it isn't, I need to work it through in my head and re-work some of the labs I have. And make it work with these kids, because they haven't had science at all, I mean very little. So, I 'll go back over the standards, and look at what we did and then go over the labs and have the kids think about it, write about it (Helen, interview, 10/8/14).

Helen discussed that she was still working through ideas in her head and indicated that she wanted to re-work her labs, but nothing specific to how she intended modify them. Later in the interview, Helen described the NGSS as a movement that provided her more freedom, but discussed an example of a classroom activity that was unclear in its relation to the NGSS.

> It going to take them a while to get it because like we didn't have this freedom…I had the kids go outside and look at the mountains one day and they said why did you do that, you don't see the mountains, and it was Mount Wilson and this was in 8th grade we were starting to talk about astronomy, its like, well you shouldn't really bring them out, the were antsy, we went out they looked and we talked for five minutes, we walked back in and they settled down. Plus they saw mountains that they, wow, those are there? Yeah they are. So I'm really excited, I'm enjoying stuff and I really hope that we don't get, I hope common doesn't mean the same. I'm experimenting and looking through stuff (Helen, interview, 10/8/14).

Helen had difficulty in articulating how she had incorporated the science and engineering practices into her classroom instruction. At times she discussed activities that were teacher-centered and mentioned that she was still thinking through how to incorporate these practices. In my observations of Helen, though, she utilized instructional strategies that pursued the goals of the NGSS, despite not explicitly describing these in her interview. The examples below describe how Helen designed instruction to provide opportunities for students to design their own experiments and share their initial ideas about a science topic.

Students designing and controlling their participation in the science practices. In my first observation of Helen, she had students finish up a lab that they had started the prior day. They were covering osmosis and diffusion and the lab intended to measure the osmotic pressure water exerts on a gummy bear when submerged in water overnight. The prior day, students had taken the initial mass of the gummy bear and set up their experiment. Now, students pulled their gummy bear out of the solution, recorded their observations of any changes to the gummy bear, and measured the mass and length of the gummy bear to calculate the change over night.

At the beginning of class, Helen asked students to predict what will happen to their gummy bear after a night in water and to explain why. After a few minutes, Helen told the class that they have two minutes to share their response with their table partners and come up with an explanation for the changes to the gummy bear. She then had the tables share their responses with the class.

> Helen: Do your predictions have to be correct?
> Students: (a few in unison) No
> Helen: Correct, they can be totally, totally wrong. So tell me what you discussed at your tables.
> Student 1: The color is going to go into the water
> Student 2: The gummy bear is going to be squishier
> Helen: Good, what process is that?
> Student 2: Osmosis
> Helen: Good, what about you [points to another table]?
> Student 3: I think it is going to expand
> Helen: Why?
> Student 3: Because the water is going to move into it
> Helen: What is that called?
> Student 3: Osmosis (Field notes, 11/18/14).

Helen told all the students that after they calculated the mass, they would average them all together. She also reminded them to write down their data and observations about any changes to the gummy bear. Helen moved throughout the room helping students with their measurements and reminding them to write down their observations. After all the groups finished, she gathered the class back together to have a short discussion about what they found and discussed how they might modify the experiment to test different solutions and the different effects different solutions might have on the gummy bear.

> Helen: So now that we have seen what a night in water has done to the gummy bear, what other variables can you think of, what other things can you, do or variables to add to our lab?
> Student 1: We could leave it another night to see what happens.
> Helen: What other substances could we use?
> Student 2: We could add a sugar cube to the water
> Student 3: Salt
> Student 4: Salt and water doesn't do anything
> Helen: We are brainstorming ideas, not judging them. Talk in your small groups and think about what else we could do to our gummy bear (Field notes, 11/18/14).

Helen wrote a few ideas down on the board: use salt or sugar in the water, use lemon juice, and leave another night.

> Helen: So what did your groups come up with
> Student 1: We could add something sour.
> Helen: What could we add that was sour?
> Student 2: Lemon
> Student 3: Alka seltzer
> Student 4: What about soda?
> Helen: What kind of soda?
> Students: (many talking at the same time, call out different kinds of soda) (Field notes, 11/18/14).

Helen wrote down all the ideas on the board and transitioned to discussing the different observations students recorded about their gummy bear.

> Helen: Other than getting huge, what was the next thing you noticed?
> Student 1: Gets like the consistency of gelatin
> Student 2: It dissolved
> Student 3: It became clear or see through
> Helen: You could see through him yesterday
> Student 3: It became more clear
> Helen: Everyone I spoke to mentioned color.
> Student 4: It became lighter and more clear

Helen: What other thing could we do that might look at color?
Student 5: We could add food coloring to the water
Helen: This is great. Tonight, I want you to go home and using the steps we did today, take one of your ideas and write up the procedure and instructions for a lab. If you want, you can try it and report back to us tomorrow what you used and what happened (Field notes, 11/19/14).

Class was ending shortly and Helen had the students clean up their tables and reminded them to be ready to share their ideas and results tomorrow at the beginning of class.

The next day, I returned to hear students' ideas and experiments. Helen quickly went over the agenda for the day and then asked students what ideas they came up with.

Helen: What is some stuff you came up with?
Student 1: I thought we could put the gummy bear in milk.
Helen: Did you do it?
Student 1: I did it this morning and wanted to leave it over night.
Helen: What do you think will happen?
Student 1: The milk will turn read and it will shrink.
Helen: What is happening if the milk turns red?
Student 1: Osmosis?
Helen: Well, osmosis involves water, so it would be the food coloring moving, right? So which is it?
Student 1: Diffusion.
Helen: Why do you think the gummy bear will shrink?
Student 1: Um
Helen: Is it just a feeling?
Student 1: Yeah
Helen: Deep down you have the answers, but just haven't learned to express it (Field notes, 11/19/14).

Helen briefly described equilibrium and how substances tended to move from areas of high concentration to areas of low concentration to help guide student thinking about why the gummy bear might shrink. She said that she had never done the experiment with milk, so she was excited to hear back from the student about her results.

Helen: Anyone else?
Student 2: I did it with tea.
Helen: What color did you start with?
Student 2: Red. I put it in at 2pm and it went for 3 hours. I came back and it turned into that big (student gestures with hand to indicate size).

Helen: What flavor tea?
Student 2: Peppermint
Helen: Did you eat it [the gummy bear]?
Student 2: No, but I drank the tea.
Helen: I was just wondering if the mint went into the gummy bear (Field notes, 11/19/14).

After soliciting a few more student ideas, Helen told the class that she collected a bunch of substances from around the school—salt, Rockstar drink, ammonia, bleach, vinegar, lemon, orange, and grapefruit juice, and food coloring and water—and set up experiments for them to look at the following day. She moved on to a different topic for the rest of the period.

Helen utilized an experiment in class to provide students with the opportunity to design their own experiment that they could conduct at home. She solicited their ideas, provided some feedback, and then allowed them to share their results from their own personal investigations. Students were allowed to select their own solutions to test and then carry out the investigation on their own at home, providing them with autonomy to design and control their participation in the science practices. While this type of classroom instruction aligned with the *designing and carrying out investigations* practice, during her interview, Helen did not describe any similar type of instructional activities as being related to the NGSS.

Reading and discussing a scientific text. In my second observation of Helen, she had students read and discuss a scientific text about genetically modified and transgenic organisms. The class period started with Helen introducing the guiding question for the day, what uses do genetic modifications have in medicine and agriculture? Students wrote the question into their notebooks and Helen handed out an article and a worksheet to guide students reading of the article. She got them started on the article and after a few minutes, she assembled the class back together to go over the template. The template included general questions that asked students to reflect on the "who, what, when, where, why, and how" (Field notes, 2/12/15) of the article. The template also included some general questions that had the students think about their opinion of the article. Helen, in her instructions, told students that they were accustomed to reading literary texts and even historical texts, but she hadn't provided them enough opportunities to read scientific texts. Scientific texts, just like historical and literary texts, have specific features that you need to understand to read. The template helped them organize their thoughts and reading of the scientific text. After this explanation, Helen gave students eight minutes to read through the article and fill out the template.

After the eight minutes, Helen told students to discuss within their table groups, the main idea of the article. After a few minutes of talking, Helen gathered the class together to share their thoughts. She reminded students that they needed to listen to one another while each table group was sharing. She called each table a tribe and had each tribe share their thoughts on the main idea of the article.

Helen:	You need to listen to everyone. You can work off of that. They may have part of it and you may have the rest of it. It is difficult for you guys, but it is a skill you will learn and worth a million bucks. Tribe 1, what is the article about?
Student 1:	GMO foods
Helen:	Technically you are right, but is there something you may want to add?
Student 1:	(shakes head no).
Student 2:	GMO and transgenic foods.
Helen:	Tribe 2?
Student 3:	GMO foods and how grapes, they put chemicals in them but they should not.
Helen:	People are putting chemicals into our foods that they shouldn't be. But is that actually genetically modified? Yes and No, but we'll get back to it. Tribe 3?
Student 4:	They put things into food
Helen:	What things? You can't say things, what things do they put in there. If

you don't know or remember that is ok. They put stuff into the food. You can go back and find out. Tribe 4?

Student 5: About if we should ban or use more of GMO foods and whether we should label them as modified or natural.

Helen: So foods that are modified need to be labeled, this has been genetically modified. Like the side of a cow. Tribe 5?

Student 6: Arguments about Proposition 37, which is about GMO and transgenic foods. Helen: Ok so you are including everything in the title, which doesn't mean you are wrong. Tribe 6?

Student 7: Some of these genetically modified foods will affect people's lives.

Helen: So it isn't all negative. It may actually help with some diseases (Field notes, 2/12/15).

Next, Helen asked students to write a summary of what happened in the article. Helen moved throughout the classroom stopping at each group to keep them on task and support their thinking. After a few minutes she gathered the class to share their ideas.

Helen: Tribe 6: what happened?

Student 1: They should put labels on genetically modified foods?

Helen: That is what happened? Think about it. I am not saying you are wrong, but think about phrasing. Tribe 5?

Student 2: People argue about genetically modified foods.

Helen: So the article is about the argument about GMO and transgenic foods. Ok, I got that. Tribe 4? *(No response from students in tribe 4)*

Helen: If you want to pass, then pass, Tribe 3?

Student 3: How the potato was grown? Can we pass?

Helen: You've learned how in a work of fiction or history to say what happened, these guys attacked these guys, or the princess met the prince, this is a completely different type of story, a lot more difficult to figure out what happened. So is it alright that you are a little bit confused. That means you are thinking, but you can't stay confused. Tribe 2?

Student 4: So companies say that things are all natural

Helen: One of the things is that they are claiming they are natural, but not really. Tribe 1?

Student 5: They explain what GMO and transgenic means.

Helen: Another thing that happens is that they make it [differences between GMO and transgenic] clear (Field notes, 2/14/15).

Helen stopped the conversation in order to try and clear up any confusion with reading the article. She discussed how her parents were farmers and how her grandmother used to save the seeds from the best crops to replant. The bell rang and Helen told students that they would continue the conversation the next day.

In this example, Helen explicitly asked students to work together to reach consensus on key ideas and characteristics of the scientific article they read in class. In her interview, Helen had difficulty articulating how her classroom instruction was different in relation to the NGSS. In my observations, though, Helen incorporated opportunities for students to control and design their participation in the science practices and incorporated opportunities for students to share and revise their initial ideas about a science topic. These types of classroom instruction closely align with the NGSS, but plausibly, these were instructional strategies that she was already using in her classroom. There was misalignment between Helen's described and observed classroom instruction, plausibly due to her developing understanding of the science and engineering practices. While her observed classroom instruction aligned with the goals of the NGSS, Helen's described classroom instruction highlighted her naïve understanding of the science and engineering practices. For Helen it seemed that she wasn't aware of any tension between how she described her classroom instruction around the science and engineering practices and how she enacted them in her classroom instruction.

These three cases—Simon, Christy, and Helen—depicted how teachers were in different places in terms of learning how to incorporate the science and engineering practices. In all three cases, there was some misalignment between teachers' described and observed classroom instruction and/or with the goals of the NGSS. This misalignment sheds light on a few specific areas where teachers needed support, clearly understanding the essential features of the science and engineering practices and aligning their classroom instruction with goals of the NGSS. Attempting to incorporate the science and engineering practices into teachers' classroom instruction placed them into a situation where they needed to understand the goals of the NGSS and then re-design their classroom instruction to meet these goals. Understanding the variation in teachers' understanding and enactment of the science and engineering practices is important for supporting their learning around incorporating the practices into their classroom instruction.

Low Alignment. In this section, I report on two case studies—Joe and James—to depict how teachers' described and observed classroom instruction do not align with the goals of the NGSS. For Joe, he articulated that he hadn't given much thought to the NGSS and found it difficult, due to various constraints, to incorporate the science and engineering practices into his current classroom teaching. He described a few activities that he thought aligned with the science and engineering practices, but most of our discussion focused on Joe trying to make sense of the practices. For James, he articulated that he was skeptical about the effectiveness of having students figure out content on their own and his classroom teaching reflected this perspective.

Joe. Joe struggled to articulate his understanding of the science and engineering practices and was reluctant to incorporate them into his classroom teaching. At the outset of my interview with Joe, he expressed that he hadn't paid much attention to the NGSS and saw some obstacles with incorporating them into his current classroom instruction.

> I planned to go do a bunch of research on the new stuff, but never got to it. I went in not knowing the NGSS. If I had seen it before, only briefly. So the PD helped a lot, in a number of things, for sure in learning NGSS. You did a great job in my opinion, because it is somewhat complex. I definitely felt I got that out of it, but I still don't know it like the back of my hand, but I know it a lot better. And how to start putting it together, a bit. The second part was so you're in school and school

get a bunch of things done, so you are already scrambling and you have this and then we come here, but as far as a complete overhaul of stuff, we just haven't done it, we have thought about a few things, but here is the deal, we started the year before the PD, with lesson plans and Powerpoints already and tests already made to the old standards. Time is limited to change all that, but we know we need to (Joe, interview, 10/6/14).

Joe felt constrained by his idea that his classroom instruction needed to be overhauled in order to incorporate the science and engineering practices. Given this perspective, he expressed reluctance to incorporate these practices because they had already started the school year and planned all their lessons and assessments. Later in the interview, I asked Joe about his thoughts on how he might incorporate the *developing and using models* practice into his classroom instruction.

Joe: We have plenty of modeling stuff in chemistry and we have no shortage of modeling, uh the whole atom thing is modeling

Jarod: But the ideas is to have kids develop and use models

Joe: Right, right to develop and modify it. I am trying to think, is that really modeling, I know it is a good thing, but is it taking a model and manipulating it and changing it… I could have them like in computer lab where they can build their own atom, where they add the parts and those different things and play around, trying to figure out how to get different chargers and stable atoms and so they get at least a crude idea of the model of the atom…but we cannot give the kids, at least not that I think of, all of the background knowledge to get the same answers of different models of the atoms that they came up with. The problem is that kids already know the current model of the atom, so they aren't going t come up with previous models like the plum pudding model. But you can certainly help them understanding how those models changed and came to change. You could show them the experiments and ask them how might you and if they come up with a good way of interpret he data that is not right, it doesn't matter if it is a good interpretation of the data. That is a great idea…every time you get some new information it changes how you put the model together. That is a classic, always has been, going over how the models of the atom have changed (Joe, interview, 10/6/14).

Joe discussed using the history of the different models of the atom to help students arrive at the current model of the atom and understand the process of its development. This type of activity reflected using models in a way that would support students in learning science content. As Joe reflected on this idea, though, the constraints around re-designing his instruction around these types of activities came to bear.

> I need to come up with something that works like that, the examples you had in there, were the classic fun, junior high examples, that you guys had in there, there might have been one that I hadn't seen, I hadn't seen, you guys have been collecting them everywhere you go. You can't have all your activities be that fun. My activities need to have a focus on what my kids need to know. I am not running out there with cool activities, but I need to focus on my content (Joe, interview, 10/6/14).

While Joe described the importance of incorporating the science and engineering practices and articulated an example that aligned with the goals of the NGSS, he struggled to articulate how his classroom instruction might look different incorporating the science and engineering practices.

During my observation of Joe, he used a traditional set of teacher-driven activities and labs around light waves. Joe lectured on the science content, then had students participate in a lab where students followed a set of explicit procedures to observe combustion reactions that emitted different types of light, and then used spectrometers to see the different wavelengths of light emitted from a few different sources (e.g., sun, florescent bulbs). Immediately after my observation, I sent Joe the following email suggesting possible ways to re-organize the set of activities to promote student discussion.

> I just wanted to send a quick note and thank you for letting me observe your class a couple weeks ago. After thinking about it more, here are some of my thoughts on how you might incorporate discussion and student ideas into light and wavelength activities you had students do when I observed.
>
> Day 1: You could start with a guiding question that captures the overarching objective for the unit. For example, how does the structure of atoms explain what type of light those atoms emit or absorb? Have student's discuss/develop a model

> of their answer. Since they know the structure of the atom (protons, neutrons, and electrons), they could put some idea together about why different atoms emit/absorb different wavelengths of light. Have them do the spectrometer activity to depict that different sources of lights emit different color wavelengths, use natural light, florescent lights, halogen lights, black lights, etc. Why do you think different lights emit/absorb differing wavelengths? Discuss your answer with your partner and decide how this might this change your original model?
>
> Day 2: Short lecture that you gave to the class when I observed. How does this information change your model? Have students share their current models (gallery walk, so that they don't have to get up and share) and reconcile any differences in a class discussion. Have students revise their model again.
>
> Day 3: Have them do the burning chloride compounds lab, to depict that different elements emit different colors. What are the differences between the elements (point to atomic structure). Finalize your model and discuss with the class.
>
> I don't know if this makes sense for what you are trying to accomplish with the few days, but here students have to develop an initial model and then revise it along the way. They discuss with partners and eventually with the whole class becoming accountable for their own ideas/models all with essentially the same activities you did with them.
>
> This is just slightly different twist on what you had them do, but it also forces students to be accountable for their ideas and have to argue/show evidence for their ideas along the way. What do you think? (email correspondence, 11/14/14).

My feedback to Joe described how he could potentially re-organize the set of activities I observed and highlighted entry points for eliciting students' ideas during these activities. The feedback was well received, but additional constraints prevented him from incorporating my feedback into his instruction.

> In general I like the teaching model applied here…it was helpful to see how you were able to structure this lesson material into this model for teaching – nicely done given the material. But, I strongly suspect students would still be underequipped in trying to think of a model using the info we give them in this plan. I hope I'm wrong about that. However, it seems that there are a few physics ideas they would need to be familiar with in order to have an idea where to begin. One that comes to mind is: planets farther from the sun have more energy (related to electron distance to the positive nucleus). I could give them lessons or experiences to fill in those gaps, but it seems like that could take a LOT of time relative to the goal (it would be more accepted in an Integrated Science class). Nevertheless, you have me thinking, and I'm sure I will try your lesson below

> and/or a modification of it next year. Also, your lesson plan has given me a clearer idea of how to apply this teaching model to other topics coming up later this year (email correspondence, 11/18/14).

In this example, Joe found it difficult to articulate his understanding of the science and engineering practices and envision how these practices might unfold in his classroom instruction. It seemed that his limited understanding of science and engineering practices brought to bear various constraints that limited his capacity to think about how to enact these practices. Providing time and support to think about the essential features of the science and engineering practices and goals of the NGSS might be a way to help Joe move past these constraints and begin thinking about how these practices might be incorporated into his classroom instruction.

James. In this example, I describe James's skepticism of the NGSS emphasis on having students figure out content for themselves. This perspective manifested in his teaching during my classroom observations. While James described instruction that pursued the goal of having students take responsibility for their learning experiences, his observed classroom instruction was largely teacher controlled. James described this idea during my interview.

> I'm not sure if any of us are sold on the idea of them discovering it for themselves. Some, like if you taught A, B, and C and they figure out D, as opposed to trying to figure out A, B, and C on their own (James, interview, 10/27/14).

He elaborated on this perspective later in the interview.

> I think that also, as far as theory goes, I don't think it is as effective. I think you have to have a base and you can have labs that have nuances, if they understanding protons, neutrons, and elections and you haven't taught them about isotopes, you can have, they can figure out isotopes, but if you are asking them to build a model and they don't know what an atom is, there needs to be a basic understanding of it, otherwise, you are saying, these people devoted their entire

> lives to find this and we want you to find it in three days. It seems unrealistic, and I haven't been sold on it (James, interview, 10/27/14).

James emphasized that students needed to have a base of knowledge in order to participate in the science practices (e.g., modeling). This perspective manifested during my first observation of James's teaching when he had students build models of atoms using playdoh.

Building models. After the class warm up, James handed each student a worksheet with a series of questions about the periodic table (e.g., calculating the number of protons, neutrons, and elections). Students were asked to fill out the worksheet, show it to him to confirm that the answers were correct, and then create a model of their element using playdoh. Students were given five minutes to fill out the worksheet. James told students that they could ask their table partners for help in figuring out how many protons, neutrons, and electrons were in their atom if needed. James circulated through the room helping students and table groups. Once students finished the worksheet, they began building their models. In this example, James asked students to demonstrate their proficiency with the content and then used the modeling activity to reinforce students' learning of the characteristics of their element. Using the science practices to reinforce content was something that he discussed in his interview as well.

> This way they have it, and they don't always have it perfectly, but they have the basis to get some of the stuff. Then you have the reinforcement activities that help solidify it, they can get their hands on it and it seems they both like science more when they get to do stuff like that and it deepens their understanding. I'm still skeptical to have projects, introduce information. I'd much rather have it reinforce (James, interview, 10/27/14).

James designed classroom instruction that largely relied on teacher driven activities where student participation in the science practices reinforced science content rather than supported their initial learning of it.

Students evaluating the content of their peers' poster presentations. During my first classroom observation, James had students prepare and present posters on research they had done on different groups in the periodic table. Students were told that they would work together to prepare a poster presentation about an assigned group of the periodic table. They were told to include information such as the groups bonding characteristics, valence electrons, and real world examples of elements in that group. At the end of class, James announced that students would be allowed to ask questions to the presenting group and good questions would earn students extra credit. This feature of their presentations stemmed from a conversation we had during his interview.

> Jarod: Have you ever had students talk about, critique or evaluate other kids?
> James: Not necessarily, I wouldn't be opposed to that.
> Jarod: Just a thought, something interesting you said that kids are presenting and sometimes they make mistakes
> James: They take notes on it.
> Jarod: Or ask questions, like I was wondering about this thing you said.
> James: That's not bad, maybe give extra credit for asking a good question.
> Jarod: Yeah, it challenges that group to make sure they know what they are talking about too (James, interview, 10/27/14).

The purpose behind this suggestion was to promote student talk during class so that students could share their ideas with their peers about the content in their posters.

I returned to James's class a week later when students were presenting their poster projects. James told students that they had five minutes to prepare and rehearse their presentations. He encouraged students to face their audience and speak loudly when they presented their information. Student presentations were very similar and followed the guidelines and questions outlined by James in his initial directions for the project. Students' posters were organized differently, but again all contained the same basic information outlined in James's instructions. Once each presentations was over, James asked a series of follow up questions such as the number of valence electrons for the elements in their group and which elements their group was most likely to react with. The one aspect of this project that wasn't scripted by James was the questions students asked of other groups after their presentations. Students' questions included clarifying questions (e.g., did you mean valence electrons rather than outer elections?), basic recall questions (e.g., are elements in group 7 reactant or non-reactant? which elements do elements in your group bond to?), and explanation questions (e.g., what types of reactions happen when elements in your group react with water? where can you find these elements in the real world?) (Field notes, 11/14/14). Once all the groups finished their presentations, James and I had a quick conversation about how he felt the question asking went.

> Jarod: So how do you think it went?
> James: Overall, I think it went well. This period was probably though one of the weakest.
> Jarod: How do you think students asking each other questions went?
> James: I actually like having students ask questions. It really challenged the presenting group to be on top of their game. Though some of the questions were kind of off, some asked some really good questions. I would definitely do this again (Field notes, 11/14/14).

During this class project, James was intentional about providing structure for students so that they could demonstrate their proficiency and understanding of the periodic table. He used poster presentations, peer discussion and student questioning to reinforce and assess students understanding of the science content covered in class. While, James incorporated my suggestion of having students ask questions about the content in their peers' posters, the function it served during my observation of the poster presentations was simply another opportunity for James to assess students' understanding of the science content they were covering. This approach does not align with the goals of the NGSS.

Summary of Findings

As I mentioned at the beginning of this section, there were three different ways to describe the relationship between teachers' descriptions of the efforts to incorporate the science and engineering practices and their enactment of those practices during their classroom instruction, high alignment, moderate alignment, and low alignment. The purpose for describing teachers in this manner was to describe the ways in which they navigated their understanding of the practices in order to enact them. At times, teachers' described classroom instruction pursued goals that aligned with the NGSS, making the science and engineering practices easy to implement. At other times, there emerged a tension between teachers' described and observed classroom instruction and the goals of the NGSS, making it more difficult to enact the science and engineering practices in ways that align with the goals of the NGSS. In this section, I summarize findings from each category of alignment.

Teachers that exemplified high alignment described classroom instruction and enacted instruction that cohered with each other and aligned to the goals of the NGSS. One common feature between Jody and Sharon was that they described and designed classroom instruction that pursued a goal of relinquishing some control within their classrooms and allowing students to take more responsibility with directing their own learning experiences. In both instances, teachers allowed students to share their initial ideas and designed opportunities for students to learn from their mistakes and revise their ideas and explanations. In both Jody and Sharon's case, they incorporated feedback that refined their classroom instruction to better align with the goals of the NGSS. The alignment between Jody and Sharon's described and observed instruction and the goals of the NGSS, facilitated their uptake of feedback because they did not need to adopt new goals and only needed to make small refinements to their classroom instruction.

Teachers in the moderate alignment category exemplified some misalignment between their described and observed classroom instruction and the goals of the NGSS. Simon, Christy, and Helen represented different misalignments within this category. Simon described instruction that pursued goals aligned with the goals of the NGSS, but his observed classroom instruction did not match up with his described instruction. Christy described classroom instruction that was slightly misaligned with the goals of the NGSS and thus designed instruction that was also slightly misaligned with the goals of the NGSS. Helen struggled to articulate how she designed instruction around the science and engineering practices, but utilized instructional strategies that closely aligned with the goals of the NGSS. These variations highlighted how teachers differentially understood the science and engineering practices. For example, Simon described a tension between incorporating the science and engineering practices and still being held accountable for student learning. The NGSS views the practices and student learning as complementary. This inconsistent view about the science and engineering practices might stand in the way of Simon using appropriate instructional strategies to pursue the types of instruction he described in his interview. Understanding the misalignment between teachers' described and observed classroom instruction can highlight specific difficulties teachers encounter in their effort to incorporate the science and engineering practices and provide insight into how to support these teachers in learning how to refine their classroom instruction to meet the demands of the NGSS.

Teachers that exemplified low alignment described and enacted classroom instruction that did not align with the goals of the NGSS. Joe described various constraints that prevented him from understanding the NGSS and thus prevented him from trying to incorporate the science and engineering practices into his classroom teaching. James expressed views that were in competition with the goals of the NGSS and thus designed instruction in ways that did not align with the science and engineering practices. Similar to those in the moderate alignment category, teachers varied in their understanding of the science and engineering practices which highlights the struggles they experience when trying to incorporate them into their classroom instruction.

For this study, my goal was to examine teachers' described and observed instruction around the science and engineering practices to understand their alignment with the goals of the NGSS. Based on the findings from my interview and observation data, there seems to be areas of alignment between teachers' described and observed instruction and the goals of the NGSS and areas where there seems to be a tension between them. While I found that in some cases, teachers found success in aligning their classroom instruction with the goals of the NGSS and appropriately incorporated the science and engineering practices, there were also cases where it seemed that teachers needed additional support. In the next section, I discuss these tensions and some opportunities to address them.

Chapter V: Discussion and Implications

The purpose of this study was to examine how teachers understand the science and engineering practices. My primary goal was to identify ways to support teachers in their efforts to align classroom teaching with the goals of the NGSS. The NGSS emphasizes student participation in eight science and engineering practices that are a drastic shift away from the content-heavy emphasis in the previous National Science Education Standards (NRC, 1996). This shift places more emphasis on what students should be able to do, rather than what students need to know. The science and engineering practices represent the content of science and the processes of science being integrated that will support deep conceptual learning in science classrooms.

My analytic focus for this study was on identifying the goals that teachers pursued and then using those goals to organize and describe the instructional strategies that teachers used while incorporating the science and engineering practices in their classroom instruction. This research is important and timely given that lead states in the national adoption of the NGSS have begun their implementation plan for the new standards. Findings from this study can inform professional development design during the implementation stage and provide insight on how to support teachers in modifying their existing instruction to incorporate the science and engineering practices in the NGSS.

Alignments and Tensions Between Teachers' Described and Observed Classroom Instruction and the Goals of NGSS

There was, unsurprisingly, variation in the extent to which teachers' described classroom instruction cohered with their observed instruction and how their instruction aligned with the goals of the science and engineering practices in NGSS. The major finding from this study was that teachers varied in ways that revealed specific tensions between traditional notions and reform notions of science teaching. These tensions highlight opportunities for professional development to support teachers developing understandings around the science and engineering practices in order to align them with the goals of the NGSS and then enact them in science classrooms. In this section, I discuss how alignment between teachers' described and observed classroom instruction with the goals of the NGSS supported their efforts to enact the science and engineering practices in the classroom and emergent tensions from the case studies reported in the previous chapter that made it difficult to enact these practices.

The alignment between teachers' described and observed classroom instruction and the goals of the NGSS reflected the specific goals they adopted and manifested in the specific instructional strategies teachers used in their teaching. Providing teachers with opportunities to confront and align their ideas and perspectives with the goals of the reform movement is a necessary step in shifting teachers' classroom instruction (Bryan, 2012). Previous research has shown that teachers' goals and knowledge about teaching and learning influence their classroom instruction (Coenders et al., 2008; Crawford, 2007; Davis, 2008). Therefore, it seems important that teachers' goals align with the goals of the NGSS in order to appropriately design classroom instruction. In some instances, there was high alignment between teachers' described and observed instruction and the goals of the science and engineering practices. For example, Sharon, and Jody designed classroom instruction to pursue goals that closely aligned with the essential features of the *developing and using models* practice in the NGSS. Sharon and Jody designed classroom activities where students were tasked with solving a scientific problem (e.g., investigating presence of color when nobody was in the room, modeling physiology of CPR) with little prior instruction. Both teachers asked students to discuss/draw their initial ideas to the problem and then provided students with additional information throughout their investigation to support their efforts to figure content out for themselves. At the end, they both asked students to come up with final models or explanations to the scientific problem. In these examples, teachers' classroom instruction closely aligned with the goals detailed in the *developing and using models* practice described in the NGSS which include ideas such as 1) models should be representations of a scientific phenomenon, 2) modeling is a repeated process of evaluation and revision, and 3) models must be based on empirical evidence.

In some instances, there was moderate to low alignment between teachers' described and observed classroom instruction and the goals of the NGSS. Moderate and low alignments resulted in classroom instruction that excluded essential features of the science and engineering practices or were in competition with the goals of the NGSS. For example, for a few teachers there emerged a tension between a notion of separation between science content and science practices and a notion of them being integrated. This tension is not new and was especially prevalent during reforms around scientific inquiry (Bybee, 2006; Roehrig & Luft, 2004; Windschitl, 2004). In this study, Christy designed instruction around having students develop and use models, but insisted that students needed a certain amount of background knowledge in order to participate in this science practice (i.e. she viewed science content knowledge as a pre-requisite to practice). In addition, Christy often supported students' investigations by giving them hints about the science content they needed to know in order to complete the task. Simon discussed a tension between creating space in his instruction to provide students with opportunities to participate in the science practices in contrast against his concern about being accountable for student learning. In addition, Simon had students build models in order to demonstrate their understanding of science content rather than utilizing the modeling process as a tool for student learning. In both cases, teachers misunderstand the perspective that learning science content and participating in the science practices are intimately tied together. The tension between a perspective that learning science content and participating in the science practices are separate versus integrated has subtle consequences for designing classroom instruction. For Simon, he utilized the modeling practice as a tool for assessing student learning rather than a tool for promoting student learning. For Christy, she provided students with background knowledge and content knowledge hints during the modeling process to support their participation in the activity rather than allowing the modeling process to build deep conceptual understanding for students.

The NGSS demands that students take the majority of responsibility for their own learning experiences, yet in this study, there emerged a tension around the teachers' locus of control and responsibility. There were varying degrees to which teachers were willing to relinquish control to students within their classrooms. Understandably, shifting control from teacher to student is difficult and brings to bear a tension rooted in conflicting views from teachers' conceptions of teaching as a learner in school and a learner in a teacher preparation program (Taylor & Booth, 2015). For example, James used a gradual release of responsibility model (Fisher & Frey, 2013) where initially he provided explicit guidance on how to investigate a topic and prepare a presentation, but as students repeated the process throughout the year, he gave them more autonomy and responsibility to make decisions around appropriate content to include in the presentation. Jody and Sharon gave students control over designing their own solutions for scientific problems without consequence and provided them opportunities to revise those solutions. Simon removed explicit instructions for an activity on modeling scientific processes as a way to press students to take responsibility for their own learning experiences. While the NGSS isn't explicit about the most appropriate way to pursue the goal of having students take responsibility for their learning experience, it seems important and productive to make teachers' goals around locus of control explicit because they seem to influence how teachers design classroom instruction.

Lastly, teachers elicited student thinking in ways that misaligned with the goals of the NGSS. It is well documented that student-teacher talk is important for student reasoning and learning. Promoting student discourse in science classrooms can lead to deep conceptual understanding (Windschitl et al., 2012; Zembal-Saul, 2009), development of argumentation skills (Kuhn et al., 2013; Ryu & Sandoval, 2012), and provide equitable access to science content in linguistically diverse classrooms (Lee et al., 2012). In this study, though, teachers seemed to be in different places in figuring out the power of student driven talk. For example, Helen included many opportunities for students to share their ideas in class, yet it was unclear what goal this instruction pursued, especially since Helen had difficulty articulating her understanding of the science and engineering practices. James provided students with opportunities to ask questions of their peers after student presentations, but this student discourse largely acted as another way for James to assess students' knowledge around the content he covered in class.

Sharon had students share their initial ideas about a science topic so that they could revise and refine their understanding of an observed science phenomenon. Depicting the type of student discourse that aligns with the goals of the NGSS might support teachers in adopting goals around students sharing ideas in class that promote productive participation in the science and engineering practices. In the next section, I discuss findings from this study that suggest ways to support teachers' efforts to incorporate the science and engineering practices into their classroom teaching.

Supporting Teachers' Efforts to Incorporate the Science and Engineering Practices

From this study, I found three salient ways to support teachers' efforts to incorporate the science and engineering practices from the NGSS. First, it is important to help teachers understand the goals they pursue during classroom instruction in relation to the goals of the NGSS. In this study, I found there were alignments and tensions between teachers' described and observed instruction and the goals of the science and engineering practices in the NGSS that influenced the appropriateness of the instructional strategies teachers used in the classroom. It seems that making teachers' goals and the goals of the science and engineering practices in the NGSS more explicit might be a productive way to increase alignment and resolve these tensions.

Second, teachers modified their existing lessons to be more open-ended (e.g., modifying verification experimental or modeling activities by not providing procedures or directions) providing students with opportunities to take more responsibility in their science learning experiences. By "opening up" their existing instructional activities, teachers found tractable ways to modify their classroom instruction to meet the demands of the NGSS. Third, feedback on teachers' lessons provided timely and actionable information on how to refine instructional activities to better align with the goals of the NGSS. Typically these discussions were informal and occurred during or soon after classroom observations or done through a series of email exchanges. Having dialogues with teachers about their classroom teaching provided them with immediate information about a lesson and enabled them to reflectively consider how to refine their classroom activities. In this section, I discuss these three strategies further and how they support teachers' efforts to incorporate the science and engineering practices into their classroom instruction.

Making the NGSS goals and teachers' goals explicit. From my analysis, I found that at some times, teachers' goals aligned with the goals of the NGSS and in others there emerged a tension between them. In alignments, teachers enacted the science and engineering practices in the ways the NGSS envisioned. In tensions, teachers appropriated the science and engineering practices in potentially unproductive and misleading ways. Helping teachers understand the goals they pursue within their classroom teaching in relation to the goals of the NGSS might support teachers in appropriately designing and refining their instructional activities to meet the expectations and demands of the NGSS.

Researchers have identified and discussed some of the salient goals of the science and engineering practices in the NGSS in terms of the language requirements to participate in discourse intensive environments around the science and engineering practices (Lee et al., 2013) and the development of "deeper and broader understanding of what we know, how we know and the epistemic and procedural constructs that guide the practice of science; the procedural, conceptual, and epistemic knowledge" (Osborne, 2014, p. 183). In addition to researchers' findings, understanding the goals of the science and engineering practices requires an in-depth reading of the practices, with an eye towards extracting the essential features that have direct implications classroom instruction (for an example done for this study, see Appendix B). A few teachers in this study had the opportunity to examine the standards in this way during my interviews with them and at times were surprised at some of the features of the science and engineering practices (e.g., developing and revising initial models of scientific phenomena). Providing structured opportunities to examine these goals might be a way to support early design of modified instructional activities or later refinements of modified lessons.

In addition, it is important to have teachers examine their own goals in relation to the goals of the NGSS. While teachers in this study did not have opportunities to do this, it seems potentially beneficial for teachers to reflect on the areas where their goals and the goals of the NGSS align in order to identify productive instructional strategies that are in alignment with the NGSS. Similarly, it also seems important to identify areas of tension between teachers' goals and the goals of the NGSS to support teachers' efforts to design and refine instruction to be in alignment with the NGSS. With that said, identifying teachers' goals is a more complex task than extracting the goals of the NGSS, given that a teacher is likely juggling multiple goals during instruction (e.g., working with a diverse group of learners, managing the classroom, making instructional decisions). One approach might be to have structured and supported opportunities for teachers to examine their existing lesson plans, identify their specific goals within the lesson, and compare those to the goals of the NGSS. This might facilitate discussions around how modify and refine lessons to pursue the goals of the NGSS.

Given these tensions and their potential ramifications on instructional design, it seems important to support teachers' efforts to align their goals with the goals of the science and engineering practices in the NGSS. It is important to design instruction with a clear and explicit understanding of the goals of that instruction and how they align with goals of reform. Designing opportunities during professional development sessions during the NGSS implementation phase for teachers to make both of these goals explicit and then provide opportunities for them to reflect on their own lessons on how to modify them to meet these goals seems important and productive given their influence on instructional design. Professional development sessions might be fertile ground to explore appropriate strategies for making these goals explicit, reconciling between teachers' goals and goals of the science and engineering practices in the NGSS, and then designing appropriate instruction to pursue them.

Opening up current instructional activities. In this study, teachers, on some occasions, utilized new instructional activities during my classroom observations, but most of the time teachers modified their existing lessons by findings opportunities to make instructional activities, such as labs, projects, and inquiry activities, more open-ended. For example, teachers opened up their lessons by having students design their own experimental procedures, develop pre-models of scientific phenomena, participate in inquiry investigations, and engage in peer critiques and questioning around science content. McNeil and Knight (2013) framed this opening up strategy in terms of having teachers pose suitable questions. Ford (2008) highlighted the productiveness of this opening up strategy through providing students resources for exploring and investigating a scientific question. Making activities more open-ended provides students with opportunities for productive disagreement and makes students publically accountable to each other.

As a result of these opening up strategies, some teachers expressed surprise and renewed motivation when students demonstrated their own renewed interest and meaningful participation in these modified and open-ended activities. Teachers found that students had genuine interests in science and had some really good ideas about how to approach finding solutions to complex science problems. Teachers also found, though, that many students became frustrated with the process of trying to make sense of science on their own. For some teachers, this brought to their attention their students lack of preparedness for these types of open-ended activities and their unwillingness to persevere through difficult situations and problems. Also, the implementation of these opening up strategies often took multiple instructional days. While teachers were willing to dedicate the classroom time because of the lack of high-stakes testing during the year of this study, it brings up the question of how this additional time investment will affect future expectations around the amount of content teachers will need to cover in a school year. Opening up activities proved to be a manageable and productive way for teachers to incorporate the science and engineering practices into their classroom teaching.

In addition, these opening up strategies afforded easy implementation because they did not require an entire re-tooling of their entire course curriculum. Currently, organizations such as the California Department of Education and National Science Teachers Association along with science education researchers (see Krajcik, Codere, Dahsah, Bayer, & Mun, 2014) have developed curriculum frameworks to support development of new curriculum for the NGSS. It is worth noting, though, that when teachers are asked to transition to a new teaching structure, time and resource constraints come to bear. This leaves me to wonder whether school structures are set up to support this transition during this new era of science education reform. What structures are in place to support this type of curriculum development? What time, resources, and support will be available to teachers to do this type of work? These time and resources constraints along with knowing that adopting and implementing new curriculum are complex and difficult tasks (Beyer, Delgado, Davis, & Krajcik, 2009; McNeil et al., 2006) may be obstacles too burdensome to overcome. Modifying existing lessons (rather than re-designing lessons or trying to implement an entirely new curriculum) to be more open-ended might be a viable alternative to developing and/or adopting new curriculum. Modifying teachers' existing lessons also affords teachers opportunities to examine the goals within those lessons, re-orient those goals, if needed, to align them with the goals of the NGSS, and then refine their instructional strategies to pursue those goals. Professional development sessions can provide supported opportunities for teachers to examine their own and colleagues' lesson plans, identify spaces where they can be opened up, and align them with the goals of science and engineering practices in the NGSS.

Actionable and timely feedback. An emerging finding within this study, but well established within the research literature, was the effectiveness of providing feedback to teachers to support improving classroom instruction. Providing high quality feedback is an important characteristic for mentor teachers in teacher education programs (e.g., Boston Teacher Residency Program, Teaching Residents at Teacher' College) (Childress, Marietta, & Suchman, 2009; Tomlinson, Hobson, and Malderez, 2010) and organizations such as the National Council on Teaching Quality (NCTQ, 2011) and

Council for Accreditation of Educator Preparation (CAEP, 2013) include providing feedback as a standard within their reform documents around improving teacher education. It seems that providing high quality feedback is an integral component of supporting the development of novice teachers, so it is plausible that feedback may be similarly effective for supporting in-service teachers' efforts to re-orient their classroom teaching.

In this study, teachers, inevitably and expectedly, pursued goals and used instructional strategies that did not align with the goals of the science and engineering practices in the NGSS. For example, in my interviews, teachers conflated the science and engineering practices with additional experiments and labs in the classroom. Increasing students' experiences with labs and hands-on activities is only a small component of these practices. In my observations, some teachers relied on traditional verification labs to get students involved in the processes of science or held whole class discussions that largely involved having students recall basic science ideas that were discussed in previous class sessions. When hearing and observing these practices, I casually discussed them with the teacher focusing on having the teacher explain to me the purpose or intent of that day's activity. A few days after, I followed up with an email that gently suggested possible alternatives for a similar type of lesson. While it was difficult to know whether my feedback directly influenced teachers' future lesson planning, I can say that in certain instances, my feedback supported teachers in thinking about how they might refine their lessons.

Feedback has been found to be useful in supporting learning when the feedback is actionable, goal referenced, and timely (Hattie, 2012). Given that my feedback occurred shortly after my observation and was focused on suggestions that could be immediately incorporated into subsequent lessons, teachers seemed open to receiving the feedback and at times inclined to incorporate the feedback into subsequent lessons. In addition, instructional coaching models suggest that ongoing feedback is a key component in supporting teachers' development (Knight, 2007). Within this study, ongoing and continuous feedback was helpful in refining teachers' classroom instruction over time.

Finding productive opportunities to give feedback to teachers within large group professional development sessions is, presumably, difficult. I found that interviews and informal conversations during classroom observations offered opportunities to dialogue individually with teachers about their thoughts and approaches to incorporating the science and engineering practices into their classroom lessons. Feedback based on classroom observations can provide teachers with a descriptive account of instruction that prompts teachers' learning processes and reflection (Khachatryan, 2015). In this study, I offered ideas tailored to each teacher's unique teaching approach and specific lesson. My feedback intended to provide instructional refinements to lessons in order to align them more with the goals of the NGSS. This feedback is productive because it is directly related to classroom teaching and it is timely because teachers had the option to incorporate this feedback immediately. These discussions tended to be informal and occurred during and after classroom observations or through a series of email exchanges. Providing actionable and timely feedback based on actual observations of classroom teaching may facilitate teacher learning and support teachers' efforts to open up their existing lesson plans to incorporate the science and engineering practices into the regular classroom instruction.

Limitations

Findings from this study should be interpreted cautiously given that the sample size was small and one of convenience. My goal was to simply describe this sample of teachers' efforts to incorporate the science and engineering practices in a way that might provide some initial insights for how teachers understand and enact the NGSS. The purpose of this study was to examine teachers' efforts to incorporate the science and engineering practices in the NGSS into their classroom teaching as a way to identify productive ways to support teachers during this new era of science education reform.

The generalizability of findings from this study is limited by the sample. Teachers in this study were volunteers and while they did not receive any payment for their participation, they were generally engaged in the initial professional development workshop and amenable to the changes proposed by the NGSS. In addition, this is a very small sample size of teachers, all working within a similar context (i.e. small urban school district), further limiting the generalizability to a larger population of teachers and teaching contexts.

The aim of this study was to provide an exploratory account of how a small sample of teachers navigated incorporating the science and engineering practices from the NGSS into their classroom instruction. I only conducted a few observations per teacher and was only able to account for a limited sample of their actual teaching practice. In addition, my observations were scheduled through the teacher by invitation further limiting my perspective on the typicality of classroom instruction I observed.

Lastly, there has been a limited amount of theoretical research around conceptualizing the demands of the NGSS and even fewer empirical investigations on how teachers understand and enact the science and engineering practices from the NGSS. This was an exploratory study where I developed my own understanding (e.g., framework) around the goals of the NGSS by reading through the standards and previous research around disciplinary engagement in science classrooms.

Implications for Future Research and Professional Development

Based on my findings, it seems that research is initially needed to develop a robust framework that outlines the goals of the NGSS. Recently, Kloser (2014) documented expert opinions (i.e. science teachers and university faculty) on the core practices for science education and the Journal of Science Teacher Education (March, 2014) published a series of theoretical articles in a special issue describing salient features of the NGSS, yet there is little empirical research that examines the underlying goals of the NGSS. While this study provided an exploratory and descriptive account of a small sample of teachers' goals on how they aligned to they goals of the NGSS, additional research is needed to understand what other instructional goals teachers pursue and how those goals align with the goals of the NGSS.

In addition, research that examines teachers' instructional goals and how they unfold during classroom instruction is needed to inform professional development design during the implementation phase of the NGSS. The NGSS explicitly states the goals and objectives for student outcomes in science classrooms, but stays away from prescribing the specific instructional strategies to attain these goals. Inherently, the NGSS seeks to restore some autonomy to teachers to make instructional decisions that are most suitable for their students and community. While this is a positive direction away from prescriptive curriculums and standardized teaching methods, research that seeks to understand effective strategies and approaches that engage students in these practices is needed. Examining teachers' instructional goals is simply the first step. Investigations that seek to understand teachers' enactment of the practices and the productive differences between them will help the research and practitioner community design professional development and establish the supportive infrastructure within districts and school communities.

From this study, I found that alignment between teachers' instructional goals and the goals of the NGSS was an important feature of supporting teachers' efforts to design appropriate instruction incorporating the science and engineering practices. Too often the goals of reform have been around changing teachers' classroom instruction. It might be more productive to understand and re-orient teachers' instructional goals in order to support them in modifying their current lessons to pursue those goals and the goals of the NGSS. In addition, I found that modifying existing lessons was a manageable way for teachers to effectively pursue their instructional goals around the science and engineering practices. Lastly, I found that supporting teachers' efforts to incorporate the science and engineering practices might be facilitated by providing actionable and timely feedback based on observations of teachers' classroom teaching. The upcoming implementation plans for the NGSS will need to rely on the findings from these investigations in order to support teachers' efforts to understand and enact the goals of the NGSS and design learning environments to meet the needs of the next generation of science learners.

Appendix A: NGSS Questionnaire

TRANSFORMING PUBLIC SCHOOLS
UCLA CENTER X

SCIENCE UCLA PROJECT

University of California, Los Angeles
Graduate School of Education and Information Studies

We are excited to partner with you and your district during the upcoming school year. In order to design our professional development activities according to you and your students needs, we have put together a questionnaire to gather inforamtion about you and your ideas about Next Generation Science Standards. Throughout the year, we will be collecting and sharing data for the purposes of refining the professional developmpent activities.

This booklet contains a series of questions organized by four sections:
1) Science and engineering practices
2) Classroom instructional practices
3) Value of argumentation
4) Background information
We will complete the first two sections on the first day of the PD (8/15/14) and the last two sections the second day of the PD (8/23/14).

Please read the instructions and each question carefully. Thank you and we look forward to working with you thorughout the year.

Name:

School Name:

Grade(s) teaching during 2014-2015 school year:

Subject(s) teaching during 2014-2015 school year:

Science and Engineering Practices

INSTRUCTIONS: The Next Generation Science Standards emphasize students learn eight science and engineering practices. By "practice" the standards mean ways of doing something. A science practice, then, is a way of doing science, or some aspect of science. For each of the practices from NGSS listed below, please describe what you think that practice means.   What does it mean by…
.

1. Asking questions (for science) and defining problems (for engineering)

2. Developing and using models

3. Planning and carrying out investigations

4. Analyzing and interpreting data

Science and Engineering Practices

.

5. Using mathematics and computational thinking

6. Constructing explanations (for science) and designing solutions (for engineering)

7. Engaging in argument from evidence

8. Obtaining, evaluating, and communicating information

Classroom Information

1. Circle the frequency with which students in your classroom (in general) participate in the following types of activities. How often do students...

	Never	a few times a year	a few times a semester	a few times a month	about once a week	daily or almost daily
graph scientfic data	1	2	3	4	5	6
generate their own questions about everyday phenomena	1	2	3	4	5	6
individually or in groups design their own experiments for investigating a scientific phenomenon	1	2	3	4	5	6
analyze secondary data they found in books, online, or elsewhere	1	2	3	4	5	6
explain their ideas to each other in small groups or to the entire class	1	2	3	4	5	6
identify/discuss evidence that supports a scientific theory	1	2	3	4	5	6
use computer simulations to understand a scientific phenomenon	1	2	3	4	5	6
identify and gather evidence to support their own claim on a science topic	1	2	3	4	5	6
develop their own explanations from scientific data	1	2	3	4	5	6
analyze primary data they gathered themselves	1	2	3	4	5	6
generate questions about something they read in or out of class	1	2	3	4	5	6
use tables or graphs to support a scientific claim	1	2	3	4	5	6
compute simple statistics with data (e.g., average)	1	2	3	4	5	6
individually or in groups conduct an experiment from a lab book	1	2	3	4	5	6
revise a model or explanation they have made previously	1	2	3	4	5	6
write a lab report to share their findings from an experiment or investigation	1	2	3	4	5	6

2. Circle the frequency with which you use the following instructional practices in your classroom (in general). How often do you...

	Never	a few times a year	a few times a semester	a few times a month	about once a week	daily or almost daily
ask students to explain or justify a scientific claim they have made	1	2	3	4	5	6
use a chart, table or diagram during instruction to illustrate a new scientific topic	1	2	3	4	5	6
discuss with students how to interpret quantitative data from an experiment or investigation	1	2	3	4	5	6
teach a lesson on how to write up scientific results in a lab report or scientific article	1	2	3	4	5	6
provide students with a series of questions they can choose from to investigate on their own	1	2	3	4	5	6
teach a lesson on interpreting statistics or quantitative data	1	2	3	4	5	6
ask students whether they agree or disagree with a students' explanation for a scientific phenomenon	1	2	3	4	5	6
discuss with students appropriate procedures for conducting a scientific experiment	1	2	3	4	5	6

Value of Argumentation

Argumentation is a core practice of scientists and at the crux of many of the scientific practices in the NGSS. For the purposes of answering the following questions, scientific arguentation simply refers to the practice of coordinating claims and evidence. We are interested in hearing about your ideas about the importance, value, and usefulness of scientific argumentation for your students. The responses will be used to inform PD sessions throughout the project. Please answer the questions in as much detail as possible.

1. How do you think students benefit from learning scientific argumentation?

2. How important do you think it is for students to learn scientific argumentation in relation to the other things you believe students should learn in science?

3. With the right instruction, can all students learn to argue well? Explain your answer.

Background Information

TEACHING EXPERIENCE

1. Counting this year as one full year, how many total years teaching experience do you have? _____

2. If you are a high school teacher, have you also taught middle school science (life, physical, or earth)?

- ☐ No
- ☐ Yes, how many years? ______

4. If you are a middle school teacher, have you also taught high school science (biology, chemistry, physics)?

- ☐ No
- ☐ Yes, how many years? ______

DEGREES AND CERTIFICATION

5. Which of the following best describes your teaching credential status?

- ☐ I am currently credentialed by California to teach science
- ☐ I am in the process of becoming credentialed by California to teach science
- ☐ Other, please specify: ______________________________

6. What was your undergraduate college major?

7. What college did you attend fo your undergraduate degree?

8. Have you completed a Masters' Degree?

☐ No ☐ Yes

If yes, please check the specialty below:

- ☐ Science Master's degree (biology, chemistry, physics, etc.)
- ☐ Science education Master's degree (from the education department and specializing in science)
- ☐ Other education department Master's degree, please specify: ____________________________
- ☐ Other Master's degree, please specify: ______________________________

Background Information

9. What college did you attend for your Master's degree, if applicable?

10. Have you completed a Ph.D. degree?

☐ No ☐ Yes

If yes, please check the specialty below:

☐ Science Ph.D. (biology, chemistry, physics, etc.)

☐ Science education Ph.D. (from the education department and specializing in science)

☐ Other education department Ph.D., please specify: ______________________________

☐ Other Ph.D., please specify: ______________________________

11. What college did you attend for your Ph.D., if applicable?

12. Please select your ethnicity (choose as many as apply):

☐ African-American

☐ Asian

☐ Hispanic/Latino

☐ Native American

☐ Pacific Islander

☐ Other, please specify: _________________________

☐ Decline to respond

13. What type of professional development opportunity might support your needs as you transition into NGSS?

☐ Engage in NGSS "model lessons"

☐ Walk through and read the standards

☐ Crosswalk (differences and similarities) between CST and NGSS

☐ Learn instructional strategies to support NGSS

☐ Time to plan (individually)

☐ Time to plan (with my colleagues)

☐ Engage in lesson study

☐ Analyze student work

☐ "Coaching"

☐ Other, please indicate below.

14. Do you have any recommendations for us as we begin planning for the next years' PD?

Appendix B: Essential Features of the Science and Engineering Practices

Practice 1: Asking questions and defining problems
- must ask questions/pose problems that are testable
- questions should lead to additional practices (investigation, research, further analysis, interpretation)
- questions are driven by critical curiosity about the world, models, theories, or investigations

Practice 2: Developing and using models
- models should be representations of a scientific phenomenon
- modeling is an iterative process of evaluation and revision
- models must be based on empirical evidence

Practice 3: Planning and carrying out investigations
- have opportunities to engage in investigations from the teacher and on their own
- investigations state the goal of an investigation, predict outcomes, and plan a course of action that will provide the best evidence to support their conclusions
-

Practice 4: Analyzing and interpreting data
- transform data into graphical representations and visualizations, and perform statistical analysis to reveal patterns and relationships
- are able to identify sources of error (e.g., experimental)
- have opportunities to analyze and interpret primary (i.e. to make a claim, develop a model, or explain a phenomenon) and secondary data sources (i.e. to confirm/dispute findings/claims/models)

Practice 5: Using mathematics and computational thinking
- use mathematics to make quantitative predictions, identify patters and relationships
- apply procedural and conceptual understanding of mathematics to scientific problems
- use digital tools (e.g., computers, calculators) to handle large data sets

Practice 6: Constructing explanations and designing solutions
- construct their own explanations from empirical evidence
- apply scientific explanations to understand scientific phenomenon
- use evidence in their explanations
- justify their evidence for scientific explanations

Practice 7: Engaging in argument from evidence
- evaluate arguments of others
- construct/advance/defend scientific claims/arguments using data and evidence
- justify their evidence for scientific claims/arguments

Practice 8: Obtaining, evaluating, and communicating information

- read and produce scientific texts
- participate in oral/written discourse around scientific topics
- critically evaluate the merit and validity of scientific texts/arguments/discourse

Appendix C: Sample Field Notes

Christy, 1/23/15, Period 2, Chemistry

21 students, 9 boys and 12 girls – (5-7 students absent because they are setting up for an assembly)

T tells me that the discussion will probably happen on Monday

848: T goes over homework and then goes over the two activities for the day. On the board she labels these as inquiry activities. First, students will make model the chemical reaction that produces water using paper clips. Make sure that you put the reactants first, not the products. That is the only instruction I am going to give you. Work in pairs. The second activity is that you are going to figure out how many moles of chalk will it take to write your name. Put together the experiment, how will you figure it out. S-how are we supposed to figure it out? T-What ever you do, put it into your report? Write it down and explain it. You have a weighing boat, chalk, and analytical balance. T- you have one question you can ask me. S-each? T-no, one question for the class. S discuss among a few and the tell someone to ask the question he came up with. S-what is the chemical formula for chalk? T-good question. Why is that important? S-so we can use it in our calculations. T-good, here you go. (Writes CaCO3 on the board underneath the word chalk)

854: Class is split into 2 groups, one that does the paper clip activity and one that does the lab. S collect paper bags with paper clips. T walks around the room.

Quick conversation with teacher
Me: You didn't give them any direction.
T: no, I want them to try and figure it out for themselves. I've done this with my AP class, but not with them. They make mistakes, but that is ok. That is the point. I want them to try and figure it out themselves, even if they make mistakes.
Me: have you done this before?
T: Not this exactly, but they have tried to do a lab on their own. They produce an entire report from title to conclusions.

S: doing the modeling activity immediately create both the products and the reactants. T reminds them that they should all do the reactants first (instead of creating all the atoms with the clips). T walks around room asking them to show them their reactants and products and how many molecules they have created. S struggle with following the directions. It seems that they might already know how to balance chemical reactions and don't' necessarily see the point of doing the activity.

One group creates 1 molecule of H and one molecule of O. T: can you combine them to make water? S: Yes but we still have an O left over? T: what can you do then. Think about the molecules. S: we need another molecule of H. T: YES! Now how many molecules of water do you have? S: two. T: yes, so what is the balanced equation look like? S: oh, 2 molecules of H with 1 O make 2 waters. Is that it? T: Yes, S: so you wanted us to balance the equation. T: Yes!

Another group – struggles with what to do with the remaining O. T: probes their thinking by asking what are you going to do with the last O?

910: Other groups working on the combustion reaction, many are outside writing their name. They all started measuring the weighing boat and then added their chalk. They have gone outside to write their name and are returning to weigh the boat and chalk. Many groups are calculating the number of moles. T reminds them that they will need to write up all their procedures and results in a report so be sure to document everything you have done.

Another group (modeling) they have CH4 modeled as C-H-H-H-H. She asks them questions about the chemical structure of CH4. T: Remember chemical bonding. How many electrons does H have to share? S look at periodic table and say 1. T: right, how many electrons does C have to share? S look back at periodic table and say 4? T: right, so look at your structure. How would you change the structure? You have H giving 2 electrons. Is that right? S: no, we need to have the H all attached to the C. T: YES! T moves to another group and goes over the same idea.

918: S show T how they did their calculations. They subtracted the masses of the before and after writing. Then calculated the molar mass and converted to moles. T reminds them that they need to write down their procedure and explain everything that they did. This is needed because the point of an experiment is to replicate it over and over again. Understand? S both nod yes.

919: Alarm goes off and groups switch activities. S: wait there are no instructions? T: oh no, what are you going to do? S; oh I get it. S goes to weigh the chalk and weighing boat.

S: we need to weigh the chalk and then go write our name (to partner). S: are you sure? S: I think so, S: tell me the mass and I'll calculate the molar mass of CaCO3.

S: do these balances have the button where you can weigh the boat and then reset. Or should we weigh both and then subtract them? T: Which one do you want to do? Which is better? Here is the button. Which do you want to do? S: which is better? T: which do you think? S: reset button. T: Why? S: I don't know, just because we don't have to do the calculations. T: ok. So this will eliminate a step and be more accurate. S; Yes.

Another group: S: we need to weigh the chalk again because I touched it and it came off on my hand so some of the mass is gone.

Group modeling the chemical reactions struggle with the same issues as the previous. They are creating all the molecules at the same time instead of using their reactants to create their products and are creating incorrect chemical structures.

Conversation with T: Didn't realize that S would create chemical structures that would be inconsistent with how they elements actually bond. T said that it was important to help S create the correct chemical structures with the paper clips.

Analytic note: Partners seems to work really well together. They seem to help each other think through the procedures and the issues they have with modeling the chemical reactions. Everyone seems to be on task as well. This might be an Honors class.

941: S begin to clean up. T reminds them that they should work on calculating the number of moles for Monday. As S are leaving, ask T if it would take 2000 moles to write their name. T: 2000 moles, does that sound realistic? Think about it.

Conversation at the end of class: I asked the T how she thought inquiry activities were beneficial for her students. She shared that the difficult part is that they get really frustrated and sometimes angry about teachers not telling them what to do, what to learn because it is "their job". But she feels that this is tied to their grade and she assures students that their grade depends on their effort and participation in the process, not necessarily the correct answer. She said this helps students feel more safe and comfortable with getting wrong answers and trying to figure things out for themselves. Today she said it was really good to reinforce chemical structures with the students (which they just learned) and she hopes that they will remember how to calculate moles, molar mass more so that if she just went up to the board and just taught it. She said that this is the way she used to do it, but finds that students enjoy these types of inquiry activities more and hopefully they learn more. On Monday she hopes to us Avogadro's number to take the activity a step further. And also she hopes that they connect that an everyday item such as chalk is a chemical compound. Now they know that.

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