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Developing K-12 Teachers' Actionable Understanding of the Multidimensional Next Generation Science Standards

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ABSTRACT

This study explored K-12 teachers' understanding and implementation of the Next Generation Science Standards (NGSS) during and after participation in a professional development (PD) program that included the development of science teachers' conceptual understanding of science. We add to the literature with our focus on a multi-year PD program emphasizing the vertical progression of concept development from kindergarten to 12th grade, rich engagement in science and engineering practices and crosscutting concepts, deep understanding of NGSS, and collaborative discussion to develop research-based pedagogical strategies to teach the three dimensions. In particular, we focus on foregrounding/backgrounding dimensions throughout a science unit to simplify instruction. Through an exploratory qualitative approach, we sought to answer the following research question: *During a three-year professional development program, how do K-12 teachers develop an actionable understanding of the intertwining three dimensions of the Next Generation Science Standards?* Teachers participating in all three years of the project were involved in school-based focus group interviews to elicit their understanding and implementation of the NGSS, especially regarding the interweaving nature of the three dimensions of the NGSS. Findings suggested that although the standards are complex, it is critical to be explicit about the three dimensions and intentional about planning for instruction. Collaboration in vertical teams and deep reflection on content and pedagogy were essential elements of the PD program. This study offers insight into the time it may take for individuals to substantially shift their daily teaching practices, underscoring the complexity of the standards and teaching shift we are asking of our teachers. Thus, foregrounding/backgrounding the dimensions throughout a unit may support teachers' actionable understanding of NGSS.

Keywords: NGSS, multi-year professional development, vertical teaming

Introduction

A Framework for K-12 Science Education (National Research Council [NRC], 2012) and the ensuing Next Generation Science Standards ([NGSS], NGSS Lead States, 2013) form the foundation of a rich vision for K-12 science teaching and learning. This framing includes science concepts, practices, and theoretical underpinnings of the development of scientific knowledge. The developers of the NGSS considered the skills needed for science education in the 21st Century, aimed to improve scientific literacy, and endeavored to create standards that lead to student understanding of big science concepts. The current framing includes three intertwining dimensions: disciplinary core ideas (DCIs), science and engineering practices (SEPs), and crosscutting concepts (CCCs).

Research suggests that teachers need professional development (PD) to support their understanding of this reform-based science teaching (Smith & Nadelson, 2017). The complexity of the NGSS results in a need for rich PD experiences—indeed, the framing of the standards presents a shift from the foci of previous standards (Nollmeyer & Bangert, 2017; Pruitt, 2014). Previous studies have examined the results of PD for teachers that focused on the new framing of the standards. Findings include the complexity of the standards posing a unique challenge (Smith & Nadelson, 2017) and how rich coaching and support can increase teachers' engagement in reform-based science teaching (Berg & Mensah, 2014).

The current study explored K-12 teachers' understanding and implementation of the NGSS during and after participating in a PD program that included the development of science teachers' conceptual understanding of science, focusing on areas within the NGSS not included in previous state standards. We add to the literature with a multi-year PD program emphasizing vertical teaming and concept development from kindergarten (K) to 12th grade, rich engagement in SEPs and CCCs, deep understanding of the NGSS, and collaborative discussion to develop research-based pedagogical strategies to teach the three dimensions. Through an exploratory qualitative approach, we sought to answer the following research question:

> During a three-year professional development program, how do K-12 teachers develop an actionable understanding of the intertwining three dimensions of the NGSS?

Conceptual Framework and Guiding Literature

Similar to the work of Nollmeyer and Bangert (2017), the NGSS framework guided the conceptual development of this study. Moreover, the crux of the current study was how the three dimensions intertwine and the theoretical underpinnings of how this is presented within *A Framework for K-12 Science Education* ([henceforth called *Framework*], NRC, 2012).

Next Generation Science Standards

The overarching goals of the NGSS involve teaching students in more authentic ways—to engage students in "doing" science rather than simply "knowing" science. The innovations in the NGSS require science educators to use new approaches in teaching (Bybee, 2015; Reiser, 2013; Stiles et al., 2017) and to shift their instruction to focus on multidimensional learning experiences (Hoeg & Bencze, 2017). The *Framework* (NRC, 2012) and the NGSS include learning progressions that begin in the elementary grades and continue through high school graduation. Unlike past science standards, the NGSS performance expectations require students to deeply understand DCIs, demonstrate the ability to show evidence of knowledge through SEPs, and connect CCCs across disciplines (Pruitt, 2014). The NGSS are guided by performance expectations that elucidate how the three dimensions can be intertwined, reflecting a view of what it means to learn science (Penuel et al., 2014). The performance expectations are essential to the NGSS because the three dimensions work together to build an integrated understanding of a rich network of connected ideas (Krajcik et al., 2014). The NGSS call for a seamless interweaving of the three dimensions, including developing scientific knowledge (SEPs) and the thought processes that allow for connections across science disciplines (CCCs). Lederman and Lederman (2013) pointed out that the NGSS are more comprehensive than previous reform documents because of their multidimensional focus. Students should demonstrate knowledge in use (NRC, 2012) and develop the ability to use scientific concepts, problem-solve, think critically, and make statements based on evidence when all three dimensions are interwoven (Krajcik et al., 2014). Furthermore, meeting performance expectations includes developing an integrated understanding of science as a body of knowledge and a set of practices and applying CCCs to deepen understanding of core ideas (Penuel et al., 2014).

Due to the complex nature of the NGSS, we anticipated that teachers would need structured support on how to understand, unpack, and implement them. Indeed, previous studies have found that teachers needed PD on various aspects of the standards (Haag & Megowan, 2015) as they have struggled to conceptualize the three dimensions (Smith & Nadelson, 2017). We thus explored how a rich PD program that focused on the multidimensionality of the standards across grades K-12 could transform into the planning of actionable teaching moves in classrooms, shifting from work with standards that focus on discrete facts to emphasizing more significant complex concepts (Pruitt, 2014).

The interweaving of the three dimensions of the NGSS is analogous to the strands of a rope (Krajcik et al., 2014). A strong rope forms when each strand is present and intertwined within science instruction. All three dimensions must be integrated; otherwise, a strand is missing, and the rope is weakened. This shift in reform-based teaching requires an actionable understanding of how the three dimensions work together to strengthen the "strands of rope" in science education.

Pruitt (2014) identified the importance of instructional planning of an entire unit with the three dimensions in mind, resulting in a coherent learning experience for students. On the contrary, a day-to-day planning approach would negate coherence. This might lead students to believe that science concepts could be more cohesive—missing the bigger picture that many concepts and skills in science are present across disciplines. Because of the complexity of the NGSS, it is vital to focus teachers' learning within the context of their classrooms (Stiles et al., 2017). Additionally, researchers identified the need for action to aid in the transition from adoption to implementation of the standards that interweave the three dimensions of the NGSS. To overcome this challenge, PD planning and resources targeting teachers could be a key component to successfully implementing the standards, advancing this new vision of science education (Sinapuelas et al., 2019). Lee et al. (2014) and Pruitt (2014) suggested that shifting from more conventional teaching practices to the practices needed to teach the NGSS effectively requires rich PD opportunities for science teachers.

Prior research on PD related to NGSS suggests the critical importance of engaging teachers in rich experiences to understand the complex nature of the framing of the standards. Indeed, while the studies reviewed explored vital aspects of PD for teachers related to NGSS, additional information is needed to better understand the needs of teachers as they delve into the complexity of the science framework.

Professional Development (PD)

Professional development (PD) is any formal activity to support teachers' further development of conceptual understanding and pedagogical skills (Desimone et al., 2002; Quint, 2012; Whitworth & Chiu, 2015). Lederman and Lederman (2013) attributed the challenges in enacting science reform efforts to insufficient support provided to teachers in the form of quality PD. Seminal research has identified the features of effective PD. If teachers are actively involved in their learning during PD programming, just as students are while in the classroom, they will develop a deeper understanding of successful learner-centered teaching (Darling-Hammond & McLaughlin, 1995; Garet et al., 2001; Loucks-Horsley & Matsumoto, 1999). Desimone (2009) proposed a framework for teacher PD that includes content focus, active learning, coherence, duration, and collective participation. Furthermore, Richardson (2003) outlined several features in the literature needed to impact teachers positively. These include a) long-term programming with follow-up (Garet et al., 2001; Luft, 2001; National Academy of Sciences [NAS], 1996; NRC, 1996; Supovitz & Turner, 2000); b) encouraging collegiality

(Jeanpierre et al., 2005; Lieberman, 1995; Loucks-Horsley et al., 1998); c) a supportive school administration (NAS, 1996; Supovitz & Turner, 2000); d) acknowledging participants' existing beliefs and practices (Darling-Hammond & McLaughlin, 1995; Garet et al., 2001; NRC, 1996); e) agreement among participants on goals and vision (Garet et al., 2001; NAS, 1996); and f) and facilitation of the PD by an outside facilitator/developer (Bell & Odom, 2012; NAS, 1996). This list of criteria provides a strong starting point for developing a PD program.

Additional research in the field has identified the following as necessary for the creation of an effective PD experience: a) academic content (Darling-Hammond & McLaughlin, 1995; Garet et al., 2001; Jeanpierre et al., 2005; Loucks-Horsley et al., 1998); b) a well-defined image of effective classroom instruction and modeling strategies (Loucks-Horsley et al., 1998; Marek & Methaven, 1991); and c) a hands-on component (Darling- Hammond & McLaughlin, 1995; Garet et al., 2001; Loucks-Horsley & Matsumoto, 1999). Furthermore, research has identified that participants value a PD program that increases conceptual understanding (Darling-Hammond & McLaughlin, 1995; Garet et al., 2001; Loucks-Horsley et al., 1998). Jeanpierre et al. (2005) stated, "providing teachers with rich content and numerous opportunities to experience the learning that they are expected to facilitate with students may serve to assist them in translating inquiry practices to their own classrooms" (p. 686).

A need exists for PD on the NGSS (Hoeg & Bencze, 2017; Lee et al., 2014; Pruitt, 2014; Stiles et al., 2017). The NGSS's complexity requires teachers to have a rich conceptual understanding of the DCIs while using appropriate strategies to make a "strong rope" for students to learn and be able to do science, thus interweaving the SEPs and CCCs. Bell and Odom (2012) and Supovitz and Turner (2000) supported this notion. These authors stated that a goal of PD should be to support the development of knowledge of both content and pedagogy to teach science using the three dimensions of the NGSS for a more authentic learning experience for students. A high-quality PD opportunity should be designed to accomplish one or more of the following goals: assist teachers in understanding the structure of the NGSS, increase pedagogical content knowledge (PCK), and/or improve teaching strategies that will strengthen the overall science experience for learners (Penuel et al., 2014).

Prior research has suggested the value of multi-year PD for science teachers, particularly related to the reforms outlined in the *Framework*. While not surprising, research has shown a positive relationship between the number of PD hours and students' science test scores (Shymansky et al., 2012). Longhurst et al. (2016) found that eighth-grade teachers who participated in a two-year PD program learned more than their one-year and non-participating peers about science reforms, integrating technology in their teaching after participating in a two-year PD program. In their five-year PD program, Shymansky et al. (2013) focused on science content, inquiry, and integrating science with literacy. These authors found that grades three and six test scores were higher than those of comparative schools. Indeed, Rinke et al. (2018) noted previous literature demonstrating that one year of PD did not suffice in impacting teaching practice and that orientations toward professional growth and collaboration were key factors that influenced the effect of science teacher PD.

One way to support collaboration is through vertical teaming or opportunities to work with teachers across grades K-12, as it can be a powerful component of PD. Vertical teaming can support deeper engagement in the content, especially when teachers experience the content as learners and in authentic contexts (Suh & Seshaiyer, 2015; Trabona et al., 2019). Gunning et al. (2020) explored K-12 vertical teaming in NGSS PD through professional learning communities. These authors found that opportunities to work across grade levels deepened in-service teachers' views of the content and the learning progression of concepts they teach. Furthermore, teachers gained a more comprehensive understanding of the purpose and context of the concepts at their grade level. Suh and Seshaiyer (2015) explored vertical teaming in PD with elementary and middle school teachers focused on reform-based mathematics teaching. Critically, the teachers in their study developed a strong conceptual and pedagogical understanding of the tasks in which they engaged, exploring common alternative conceptions and expectations for each grade level

Our research used previous understandings of effective PD to examine how a three-year PD project influenced K-12 teachers' actionable understandings of the three interweaving dimensions of the NGSS. We contribute to this research base by focusing on three critical elements of NGSS PD: learning progressions from K-12th grades, multi-year engagement with teachers, and collaborative discussion to develop research-based pedagogical strategies to teach science using the three dimensions. Critically, we do so by emphasizing the foreground/background instructional approach (Bybee, 2013) to help teachers manage the complex nature of the NGSS.

Methods

We used a qualitative, exploratory design following what Merriam (2009) describes as one that "uncovers[s] and interprets[s]…how meaning is constructed, [and] how people make sense of their lives and their worlds" (p. 24). We explored how teachers learned about and understood the complexity and multidimensionality of the NGSS and how that learning helped inform and shape their practice through a multi-year and vertical teaming PD experience.

Participants

The district science coordinator, an active member of the PD team, invited expressions of interest in the project from teachers at schools that served large percentages of low-income students (i.e., most of the schools in the district). One condition for the study was participation as a group—at least two teachers from the same school in a common professional learning community team. Because these logistics were somewhat intensive in time and the number of busy professionals to engage (three-year time span, multiple teachers in the same school), the project included 11 schools that committed to participation. In Year One, teams of teachers (between two to four per school) from the 11 schools participated: two high schools (five teachers), four middle schools (12 teachers), and five elementary schools (15 teachers). See Table 1 for this information.

Table 1

Overview of Participating Schools (2021-22 Data, from District Website)

School ID	Student Population	School Rating: Red (lowest), Orange, Yellow, Green, Blue (highest)	Economically Disadvantaged	Student Demographics
1	1352	Orange	77.1%	47.8% Caucasian 26.1% Hispanic/Latino 19.3% African American 6.8% Other
2	2330	Red	76.0%	31.5% Caucasian 24.2% Hispanic/Latino 36.4% African American 7.9% Other
3	979	Green	45.7%	35.4% Caucasian 27% Hispanic/Latino 26.6% African American 11% Other
4	502	Yellow	57.2%	78.5% Caucasian 8.4% Hispanic/Latino 6% Two or more races 7.1% Other

Table 1 *continued*

School ID	Student Population	School Rating: Red (lowest), Orange, Yellow, Green, Blue (highest)	Economically Disadvantaged	Student Demographics
5	1289	Green	51.8%	46.6% Caucasian 8.8% Hispanic/Latino 31.5% African American 13.1% Other
6	989	Orange	71.2%	40% Caucasian 12% Hispanic/Latino 36.9% African American 11.1% Other
7	446	Orange	76.5%	23.1% Caucasian 33% Hispanic/Latino 32.3% African American 11.6% Other
8	514	Red	85.2%	9.9% Caucasian 33.7% Hispanic/Latino 46.9% African American 9.5% Other
9	299	Red	90.6%	5.4% Hispanic/Latino 86% African American 4.7% Two or more 3.9% Other
10	410	Red	85.9%	13.7% Caucasian 29.5% Hispanic/Latino 48% African American 8.8% Other
11	313	Orange	74.8%	18.5% Caucasian 18.5% Hispanic/Latino 48.9% African American 14.1% Other

As noted at the end of this section, the district also incorporated expertise and lessons learned into their district-level efforts to disseminate project-influenced resources to all schools in the district.

In some cases, school teams included a science coach who worked with the teachers at their school. The science coaches were based at each school site and were responsible for supporting teachers in the planning and instruction of science units and lessons. The level of teaching experience of participants ranged from novice teachers (1-3 years) to veteran teachers (20+ years). The schools generally had below-average academic performance in the district, and teachers seemed enthusiastic to participate in the project.

In Year One, all participants engaged in the same PD experiences that focused on the three dimensions through inquiry-based experiences about the architecture of the NGSS, the science concepts in the NGSS, and pedagogical strategies for teaching using the NGSS. In Year Two, one high school (three teachers), three middle schools (seven teachers), and five elementary schools (nine teachers) continued participation. For Year Three, based on the request by the high school teachers who indicated that they felt like they had gotten what they needed from the project, the project refocused on only elementary (six schools; 16 teachers) and middle schools (two schools, eight teachers). Approximately one-third of these Year Three teachers were new to the project due to shifts in teaching assignment grade levels and schools. These changes, driven by teacher participant requests, allowed the project to focus more strongly in Year Three on additional support for pedagogical strategies and related content knowledge deepening.

Furthermore, elementary and middle school participants requested a focus on concepts with which the high school teachers expressed that they were already comfortable. Because the project's first two years significantly focused on the vertical teaming and the learning progression of the standards, this change to include only elementary and middle teachers in Year Three did not substantially impact the overall project goal of emphasizing vertical alignment. See Table 2 for more information on the PD components.

Table 2

Connection between PD Program and Literature

Connection to Literature	PD Component
Active learning/hands-on (Darling-Hammond & McLaughlin, 1995; Garet et al., 2001; Loucks-Horsley & Matsumoto, 1999)	Teachers experienced inquiry-based activities related to DCIs, SEPs, and CCCs in NGSS (e.g., teachers created a "human wave" to model amplitude and frequency, and energy transfer)
Increase content knowledge (Darling-Hammond & McLaughlin, 1995; Garet et al., 2001; Jeanpierre et al., 2005; Loucks-Horsley & Matsumoto, 1999)	PD experiences focused on DCIs, SEPs, and CCCs that were challenging and not included in previous standards (e.g., waves, Energy, particle-level modeling of matter)
Bridge the gap between PCK and pedagogy (Bell & Odom, 2012; Supovitz & Turner; 2000)	PD included examination of student work and work in professional learning communities to collaboratively discuss science teaching and learning
Long-term follow up (Garet et al., 2001; Luft, 2001; NAS, 1996; NRC, 1996; Supovitz & Turner; 2000)	The PD program was three years long; science coaches were instructed to share ideas and concepts with teachers not involved in the project
Collegiality (Jeanpierre et al., 2005; Lieberman, 1995; Loucks-Horsley et al., 1998)	Teachers sat in school groups and vertical (K-12) teams; teachers worked in mixed-grade groups during hands-on inquiry to get to know one another and build knowledge of NGSS learning progressions
Supportive administration (NAS, 1996; Supovitz & Turner, 2000)	District specialists led the PD, and district and school administration supported the PD program
Acknowledgment of participants' existing beliefs and practices (Darling-Hammond & McLaughlin, 1995; Garet et al., 2001; NRC, 1996)	Formative assessment probes (Keeley, 2008) supported assessment and modeling of content knowledge and teaching practices; PD included discussion of existing practices that could be tuned to more tightly align with NGSS, rather than suggesting teachers needed to start from scratch
Academic content (Darling-Hammond & McLaughlin, 1995; Garet et al., 2001; Jeanpierre et al., 2005; Loucks-Horsley et al., 1998)	PD focused on DCIs that were new or particularly challenging for teachers. These were selected based on teachers' stated needs
Teaching and modeling of strategies (Loucks-Horsley et al., 1998; Marek & Methaven, 1991)	Teachers experienced inquiry-based activities related to DCIs, SEPs, and CCCs in NGSS (e.g., teachers created models of particle-level behavior of matter, including energy considerations)

By the third year, teachers expressed (and the PD team agreed) that they had appreciated the inclusion of vertical teaming work earlier in the project and found it valuable, but the elementary and middle teachers would benefit best from a more exclusive focus on content and pedagogy in their respective grade levels. In the transition from Year Two to Year Three of the project, four of the school-based science coaches were moved to the district offices to work on writing units that adapted the district science curriculum to align with the NGSS and to support teachers at schools across the district. These four district-level individuals continued to participate in the PD.

Professional Development Experiences

The PD experiences were strategically planned to enhance teachers' conceptual understanding of science, to teach how the standards progress vertically from K-12, and to address how the three dimensions of the NGSS interweave. Furthermore, the experiences were designed to support teachers' planning of intertwined three-dimensional instruction (see Table 2 for connections between components of the PD program and previous literature).

The PD team consisted of the district science coordinator, an elementary district specialist, two university chemistry professors, a secondary science education professor (Tom, third author), and an elementary science education assistant professor (Ingrid, first author). A high school science coach also participated in some of the team's planning sessions. The CCC of Energy was the overarching theme of the entire project, embedded throughout all the PD experiences. The PD also incorporated content (DCIs), SEPs, and other CCCs. All of these were discussed within the broader concept of Energy. Please see Tables 3 and 4 for descriptions of typical PD activities and an overall summary of the PD timeline and foci.

Table 3

Typical PD Activities and Differentiation Structures to Meet Teacher Needs

Typical PD Activities	**Differentiation for Teacher Needs**
Lived 3-D experience as a learner (e.g., modeling waves in multiple ways and articulating energy relationships to amplitude and frequency)	Heterogeneous groups (elementary, middle, and high school teachers) with 'as needed' input, questions, and responses from PD leadership team at group level for easy and frequent access
Unpacking the lived experience (e.g., identifying multidimensionality, articulating pedagogical strategies incorporated, considering how to modify or focus for different ages or abilities of learners)	Grade-alike groups. This was especially helpful for the pedagogical group-level conversations and discussions for modifying for different ages or abilities or prior knowledge of students. A PD leader participated with each group
Examining learning progression of standards (e.g., how concepts build in sophistication as students get older, how one might review to reinforce presumed previous learning and link new learning to prior)	Heterogeneous groups (elementary, middle, high school teachers). Within-group conversations of likely student uptake of concepts, likely needs to reinforce (or teach) prior learning, leveraging SEPs and CCCs over years of schooling
Planning to implement near-future lessons (DCI target of lesson to be determined by teachers according to their curriculum)	School-based PLC groups, including, when available, the school-based science coaches. Incorporated existing curriculum materials (e.g., FOSS kits) when available
Examining student work (teachers bringing samples of student work from prior cycle implementation)	Combination of grade-alike and heterogeneous groups. Grade-alike to synthesize and summarize student work, then sharing in heterogeneous groups so teachers get a snapshot of student thinking in adjacent grade bands

Table 4

Summary of PD Timeline and Foci

Year	Month	Activities
1	April	2-day PD on formative assessment
1	June	Online support through the district system: Posting of lesson plans and student work, question and answer with project leaders
1	October	Two 1-day PD sessions: 1) Focused on science content related to fields, professional learning communities, scientific argumentation, and examining student work; 2) Revisited concept of fields, focused on professional learning communities and systems and system models
2	February	Two 1-day PD sessions: 1) Focused on science content related to fields, professional learning communities, scientific argumentation, and examining student work; 2) Revisited concept of fields, focused on professional learning communities and systems and system models
2	June	Online support through the district system: Posting of lesson plans and student work, question and answer with project leaders
2	June	5-day PD on waves, models, and digital communication systems
2	August	Series of two 1-day PD sessions targeting: 1) Sharing and interpreting student work on common topics planned at the prior session; 2) Science content of matter and Energy at particle level as well as magnetism; 3) Crafting arguments from evidence; 4) Designing and conducting investigations
3	May	Series of two 1-day PD sessions targeting: 1) Sharing and interpreting student work on common topics planned at the prior session; 2) Science content of matter and Energy at particle level as well as magnetism; 3) Crafting arguments from evidence; 4) Designing and conducting investigations
3	June	5-day PD on states of matter integrated with energy considerations and practice of developing and using models

Professional learning communities ([PLC], Dufour, 2004) were implemented in Year One. Project participants engaged in three PLC cycles throughout the school year with either their school-based team or the same grade band teachers. These consisted of planning a standards-based lesson, teaching the lesson, and collaborative reflection on the lesson through analysis of student work. Participants were instructed to focus on one of three topics for each cycle: Energy, scientific argumentation, or systems and system models. The purpose of asking participants to engage in PLCs was to allow teachers to co-plan and teach lessons incorporating the NGSS and to collaboratively examine student work regarding specific DCIs, SEPs, and CCCs.

Data Sources

Participants in all three years of the project participated in school-based focus group interviews to elicit their understanding and implementation of the NGSS, especially regarding the interweaving nature of the three dimensions of the NGSS. Focus group interviews were conducted immediately following the Year Two five-day PD on waves and models and again immediately following the Year

Three five-day PD on states of matter. Ingrid and Tom (authors 1 and 3) conducted Year Two interviews, which included six focus groups; William and Tom (authors 2 and 3) conducted Year Three interviews, which consisted of three focus groups (see Appendix A for interview protocols). Interviews were not conducted after Year One because formative assessment information from throughout the first-year summer PD guided the leadership team to judge that teachers were still growing in their understanding of NGSS instruction. An interview may have unintentionally emphasized areas uncomfortable for teachers at this early stage of development and left a negative impression on teachers' perceptions of their progress.

Data Analysis

Interview data from Year Two was fully transcribed and analyzed using open coding (Creswell & Creswell, 2018; Merriam & Tisdell, 2016; Saldaña, 2013) to elicit emergent themes. Year Two analysis focused on themes related to understanding the three dimensions of NGSS. Ingrid and William (authors 1 and 2) open-coded the data individually and then discussed emergent themes together. Axial coding resulted in the themes that were consolidated into the following foci: understanding the complexity of the standards, utility of Bybee's (2013) foreground/background approach, pedagogical growth in understanding of how to teach the NGSS, and collaboration/vertical teaming. Ingrid and William then coded Year Two interview data for these four themes and discussed their coding.

After Year Three data were collected, audio files were fully transcribed, and Ingrid and William coded using the four themes that emerged from Year Two interviews. Ingrid and William quickly realized that new themes were evident and that the previous four could be refined. They revised the Year Two themes to be more specific and to include new components of Year Three interviews. See Table 5.

Table 5

Themes and Codes Applied to All Data (Year Two and Year Three)

Theme	Subthemes
Complexity of the Standards (C)	Complexity of interweaving the three dimensions (IW) ● Foreground/Background (FB) ● Intentional (I) ● Explicit (E) Complexity of the content itself (COM)
Collaboration (Col)	Vertical progression/teaming (V) PLC work (PLC) Providing PD support to teachers and/or observing peers (SUP)
Reflecting on Teaching (R)*	Thinking about past instruction (PI) Having low PCK and/or gaining PCK new content/misconceptions (PCK)
Reflecting on components of PD (PD)	Product - learning content (PROD) Process - thinking about content in new ways (PROC) Pedagogy - classroom implications (PED)

Note. *Subsumed within other themes in the "Results" section for clarity

Due to the complex nature of the Year Three interviews and the large number of codes, Ingrid and William engaged in collaborative coding (Smagorinsky, 2008), discussing each talk segment and determining together the best code for the talk segment. All interview transcripts were discussed in-depth, and in cases where no codes fit the segment, Ingrid and William labeled it "no code". Initially, two Year Three transcripts were coded collaboratively in their entirety. Once Ingrid and William felt more comfortable in their mutual understanding of the codes, the remaining transcripts (six from Year Two and one from Year Three) were coded individually and then discussed/coded collaboratively. Patton (2015) notes the importance of trustworthiness, credibility, and dependability of data analysis. Indeed, we spent much time with participants within the PD activities and during interviews. To support dependability, we followed a systematic process of allowing themes and codes to emerge from the data. Table 5 provides an overview of the themes and codes that emerged from the data.

Results

The following results are based on the coding scheme summarized in Table 5, and are organized by the emergent themes of complexity of the standards, collaboration, and reflecting on components of the PD. For clarity, data that were coded as "*reflecting on teaching*" was subsumed under the other three themes.

Complexity of the Standards

Some teachers initially felt overwhelmed by the complexity of the NGSS, especially regarding the three dimensions—how to interweave them and how they built up to the performance expectations. After Year Two, however, teachers were beginning to understand the complexity and multidimensionality of the standards. An elementary teacher noted,

> [N]ow this week I see the benefit of really trying to make sure that you are doing the 5Es…just really being intentional about how you present the material and really being intentional about making sure you apply the DCIs, the crosscutting [concepts], and the practices. I am starting to make those connections, where now I see the big picture, where at first, I was kind of confused (*C-IW-FB-I and C-IW, Year Two*).

Teachers stated that while previously only emphasizing the content, they now understood the importance of the other two dimensions and interweaving them to form a cohesive "rope." One elementary teacher noted, "But what really drove home to me is now taking it all and making it one piece, versus all these different pieces of the puzzle" (*PD-PED, Year Two*).

Furthermore, an elementary teacher noted how she previously focused only on content but now understands the importance of all three dimensions of the standards.

> One thing that has influenced me is to not just focus on that orange box [DCI], because I think that's where we all tend to go, so I think this has really helped me focus on that green [CCC] and blue [SEP] box, and recognize that they are all three equally valuable, and to drive that content home in order to meet the performance expectations, so that was huge for me (*C-IW, Year Two*).

The PD experiences, therefore, clarified how the NGSS differed from previous state standards and how they now contained various "threads" that must interweave to build into the ultimate learning goals and complexity of the performance expectations. For many teachers, there seemed to be two phases of understanding during the PD: the NGSS had to be "unpacked" and evaluated as individual parts, and those parts then had to be weaved back together into an instructional whole. These phases seemed to cement a fuller understanding of the NGSS for teachers.

Explicitness and Intentionality

Regarding the multidimensionality of the standards, teachers stated that they had a clearer understanding of being explicit with their students about the three dimensions during instruction and being intentional about including them in their planning. Thus, *explicitness* refers to being direct and naming the actual DCIs, SEPs, and/or CCCs in the lesson. *Intentionality* refers to paying attention to incorporating all three dimensions while planning science lessons.

In the PD program, Bybee's (2013) concept of foreground/background was used as a framework to understand explicitness and intentionality. The foreground/background stipulates that in any given lesson or unit, select dimensions of the NGSS can be explicitly emphasized while others are attended to more implicitly. Using this approach to think of the complexity of the standards, the teachers began to conceptualize how and when to make various dimensions of the NGSS explicit. The teachers noted the foreground/background framework for the three dimensions and how beneficial it was to interweave them into one lesson or unit. As mentioned previously, teachers stated that they had formerly emphasized the content, as this was the focus of the previous state standards. They noted the importance of the other dimensions of scientific knowledge and how understanding the NGSS helped them conceptualize how to address their full scope.

> The foreground/background that we were all talking about…in previous years you're always so focused on the content, the content, the content, and by doing this it's allowed you to realize that you can focus on something else, and they still get the content. But our focus would be a crosscutting concept or developing a model or something along those lines instead of just that DCI. As a teacher you sometimes get to that overwhelming point of 'we have to teach this, and this and this and this and how do I fit it all into one school year?' So that was really beneficial (*C-IW-FB, Year Two*).

This quote suggests how the teachers believed the foreground/background approach would allow them to emphasize other dimensions of the NGSS beyond the DCIs. This view differed from prior instruction that focused solely on content. An elementary science coach noted that while the district has long been promoting and supporting inquiry-based science, the adoption of NGSS required teachers to be more clear about how students are engaging in the science practices: "We've been doing FOSS modules and investigative science and inquiry for a long time in the district so the practices are easier for them to see, but being explicit about them, we're getting there now" (*C-IW-FB-E, Year Three*). Likewise, a middle school district science coach emphasized the importance of a "name it and claim it" approach—in other words, being explicit with the students about the DCIs, SEPs, and/or CCCs connected to the lesson. One elementary teacher reflected on the importance of being explicit about the dimension she is foregrounding.

> And just being explicit with, um, talking to our students about modeling or cause and effect, or ya know, those other sides of the standards that aren't just the content piece but being real explicit in what we are saying and making sure that they are getting the point of an investigation or um, the activity in class (*C-IW-FB-E, Year Three*).

Regarding intentionality, teachers noted that to emphasize various dimensions of the NGSS, they needed to be purposeful in their planning. A middle school teacher reflected on her past teaching and stated the importance of being deliberate in her planning to include all three dimensions of the standards. She had previously discussed the SEPs and CCCs sporadically but will now be more intntional about focusing on these two dimensions.

> It's really deepened to a level of looking at like the DCI, and then looking at the engineering practices and then looking at your crosscutting concepts, but us really going through and doing those, and actually right now I feel better in the sense of like, what you said about being more intentional.

An elementary science coach spoke about how the PD would impact her as she developed the instructional units to be taught by teachers. She realized that she had to be more intentional and explicit as she wrote the units to guide teachers toward being explicit with their students about the dimensions of the standards.

> So, being very intentional in your planning… we've tried to be intentional with that foreground/background thing that [PD team member] brought up about definitely the DCIs are in the foreground kinda constantly when we're planning those units, but we've really tried to pull some of the practices into the foreground, and we would put teacher notes in those instructional units that say, 'the purpose of this is to intentionally focus the students on scientific writing…' but again it's letting the teacher know, but we didn't do a good job letting the teacher know that they need to intentionally teach that this is what they're doing (*C-IW-FB-I, Year Two*).

In this quote, the elementary school science coach reflected on how she planned to embed specific language to indicate to the teachers that they must be explicit in their discussions of the three dimensions. Thus, she planned to be intentional as she wrote units for the district. She noted that she had to be more purposeful about guiding teachers to verbalize reference to the three dimensions so that students knew when they were engaging in the SEPs and CCCs. This highlighted for the PD provider team the importance of explicitness and intentionality across multiple levels of teaching—in planning and delivery of PD experiences, by district science curriculum writers in communicating to classroom teachers who would use that curriculum, and by classroom teachers to explicitly teach SEPs and CCCs to their K-12 students. An unbroken chain of explicitness and intentionality seemed necessary to ensure that the ultimate multidimensional learning goals for students would be within reach.

Collaboration

Throughout the first two years of the PD program, teachers met in K-12 teams to discuss student work, examine content knowledge, and work with the standards. When discussing the benefits of collaboration, teachers noted the value of working in K-12 vertical teams and giving and receiving support from their colleagues. In the summer PD of Year Two, teachers physically mapped out the learning progressions of standards, examining and posting concepts linearly around the room to indicate how concepts deepened across each grade band. This helped many teachers understand the conceptual progression of the standards, gaining insight into what students needed to know both as a foundation for the specific concepts they teach and what students would be learning after their grade level.

Vertical Teaming

Teachers noted the importance of vertical teams (working in groups of K-12 teachers) and understanding the full spectrum of students' K-12 learning experiences. One elementary school teacher noted that she did not realize that the elementary science concepts were at such a simplified level and how complex the content became as students progressed to middle school.

> Well, I always think of, like when they were saying yesterday, like [indistinguishable] teaching waves in 4th grade and how much they have to know for the chemistry aspect in middle school, I mean it was pretty amazing when we were kind of like 'what did this experience, what concept were we trying to get?' I mean, I just thought it was funny, we're so broad and basic because that's really elementary, and then how narrow and focused [secondary teachers] were with what they thought the concept was, I mean, ya know it's the same thing, it's the same words but it's how you say them. And, just, it's just more complex as they get older and that was an eye opener for me (*PD-PROC, Year Three*).

This elementary teacher realized that the foundational knowledge she taught in fourth grade was critical to the concepts that were taught in later grades. Similarly, a high school teacher reflected on the importance of collaborating with K-12 teachers, thus gaining a deeper understanding of what students should learn before taking his class.

> And then another thing I thought that we learned that was very significant to me was what students should or would be doing in the vertical progression, because it helps me know what they should have seen, what they should understand, where they're coming from, and where we're getting them to. And it makes a really big difference to me knowing that they should have been introduced to waves in 7th grade, or they will be getting introduced to waves, that way I don't have to go over this is what a wave is and the very basics (*COL-V, Year Two*).

The teachers discussed that the K-12 nature of the PD gave them a better understanding of what their students needed to know, and it helped them build their content knowledge or understand the content in new ways. An elementary teacher noted the importance of verticalteaming to develop her content knowledge.

> But the big takeaway for me is the content knowledge and sitting K-12, because sitting with just elementary, there is a ceiling [with regard to content knowledge]. There is not as much of a ceiling when you have K-12 and when you have university specialists (*COL-V, Year Two*).

This data indicates that the opportunity to work in K-12 teams was a valuable part of learning about the standards, developing their content knowledge, and understanding the learning progressions of the concepts within NGSS.

Providing Support

Another critical aspect of the PD included teachers providing support for one another. The PD team explicitly planned some of this support, for example, the expectation of conducting three PLC cycles throughout Year One and participation in PD days during the year to examine students' work. The teachers noted that the PLC work supported their understanding of teaching the NGSS and the importance of embedding SEPs and CCCs. Recall that teachers were asked to focus on one of each of the three cycles on Energy, scientific argumentation, and systems and system models. The high school and elementary teachers stated that working in these PLC cycles allowed them to compare content across subject areas (i.e., high school physics to high school chemistry) and to impact students' learning. One elementary teacher spoke about the power of collaborating with the school science coach in the planning and teaching of a lesson focused on systems and system models.

> I think [teaching about systems] made the most impact on my kids because throughout the year they kept saying, 'I remember when we went out with [school science coach] and we did this animal dispersal. You know, I think that made a big impact on them (*COL-SUP, Year Two*).

In Year Three, the district science coaches reflected on their role in supporting the teachers in the project and the other teachers in the district. In addition, district science coaches reflected on their roles in developing instructional units for teachers from the current curriculum. They stated that they had worked directly with teachers in the classroom to support understanding and, in the future, they will presumably support the implementation of the new standards.

> So, um, a lot of our work this year has been helping teachers [who are not in the program], kind of where we started three years ago…getting teachers to dig into the appendix, dig into the progressions, look at vertical, the vertical progressions (*COL-SUP, Year Three*).

The coaches knew that participation in the project was not extended to all teachers in the district; therefore, their role was to support teachers not involved in the project to understand the standards and intentionally plan for and explicitly teach the three interweaving dimensions.

Reflecting on Components of the Professional Development

The final theme evident in the interviews was reflection on the various components of the PD. Teachers reflected on their understanding of content, learning new concepts, and thinking about content in new ways. Teachers also reflected deeply on how the PD would affect their future teaching and pedagogical practices.

Content

An essential goal of the PD project was to build on teachers' content knowledge, especially concepts related to Energy, other concepts from the NGSS that were absent in the previous state standards, and understandings of the three dimensions. Many of the elementary teachers reflected on the content that they learned in the program, even though some stated that they struggled with understanding at the level of the middle and high school teachers. One elementary teacher reflected on the importance of content knowledge when teaching and how having a deeper understanding could support her students' learning.

> But it was nice to be able to learn more myself to be able to go beyond that, in case the kids start probing or asking more questions, and I would be able to push them along and enlighten them a little further (*PD-PROD, Year Two*).

Furthermore, the teachers noted that the PD helped them learn new content and understand it in new ways. This was most evident regarding the content of waves (as this content was not explicit in the previous state standards) and how to incorporate the CCCs. One elementary school science coach said,

> What helped me the most was the content knowledge for the week of Energy [Year Two] and the content knowledge for the week of waves [Year Three], and setting the parameters of what really defines a system, and how I am going to get that to an understanding for an elementary

> teacher, and a model, the same thing, because we tend to think of models and making a model of a cell, or a volcano, and that's the only kind of model we can have (*PD-PROC, Year Two*).

In Year Three, a district science coach stated that teachers must discuss models and the limitations of models—an idea that was also discussed during the PD on waves in Year Two. This teacher reflected on how she used to teach specific content using models; however through the PD, she gained new perspectives on teaching models and systems. She began to see waves as a model, perhaps about an activity during which we modeled components of waves using our bodies and body movement.

> So, thinking about, ya know, you can't just build your model. You've got to discuss limitations, you've got to revise it, you've got to use it, ya know, those kinds of things. So we've designed different activities that we've used in PD in terms of how the teachers work on that piece of it (*PD-PROC, Year Three*).

The teachers stated that while much of the content they needed to teach from the NGSS was not new, they had yet to think of it through the lens of the CCCs. Recall that the PD focused on the CCCs of Energy and Systems and System Models. The teachers stated that while they had previously taught about Energy or Systems, they had yet to do so in a way that the concepts were interwoven with the DCIs. One high school teacher said,

> So, I think in the future…I'll be able to look at models as a much more important starting point for instruction. I'll be able to look at the engineering practices and the argumentation as more crucial and happening all the time. After last summer, I felt like my understanding was stuck with Energy and everything we did was about Energy. And when we did systems, I tried to put systems in other places as well, but it really felt much better in just Energy. Whereas I think models, I can really put anywhere in my instruction (*PD-PROC, Year Two*).

This quote indicates that the teacher was thinking about the content in new ways, as he could ground his lesson in a CCC rather than a DCI.

Pedagogy

A significant theme in the data included reflection on how teachers planned to teach or were teaching with the NGSS. Indeed, one of the interview questions in both Years Two and Three directly asked teachers how the project influenced their thinking, planning, and teaching of the NGSS. The teachers reflected on their ability to adapt what they already did to align with the NGSS and interweave the standards' three dimensions. During the Year Two interviews, one high school teacher noted,

> And I think that as a teacher what I can really do is take the lessons that I do already and with some fairly quick analysis, figure out how to be more explicit with my students that what they're doing is NGSS. It's not going to be new content necessarily, but a lot of it's overlapping from before, it's just new emphases (*PD-PED, Year Two*).

This reflection on how he could infuse his prior knowledge of content and the curriculum with the new concepts of the NGSS indicated that his understanding of the NGSS included the three dimensions. Moreover, he suggested that the NGSS were not entirely new—they included new (and perhaps additional) areas of emphasis. Another high school teacher explained how he viewed these new areas of emphasis.

> With systems, I never really looked at that as something to include in my instruction... systems simplify things for the students and models make them visible to the students. In chemistry, there's a lot of complicated things happening and there's a lot of things you can't see. I think really systems and modeling is going to be very impactful on my instruction. But it was tough the first time around, 'Okay now's the time I have to do systems. What lesson is this? Okay let's make it systems.' As opposed to the other way around, let's take a systems approach and fill in the lesson, and thinking about them this way. It almost felt like when does it come? It comes now? Okay, we'll do it with endothermic/exothermic. It made sense then, but it still, like you said, felt forced a little (*PD-PED, Year Two*).

This high school teacher reflected on his past instruction and noted how he planned to approach his future instruction. Initially, he was trying to include systems in a lesson, whereas he had reversed his thinking into beginning with a systems approach and seeing how the lesson fit in with systems. This reversal of how he thought about the lesson indicated that his pedagogical thinking had shifted as he interweaved threads of the three dimensions and changed the emphasis of the lessons.

Discussion

The findings of this study indicate that focused and extended (in this case, three years) PD can foster teachers' understanding of the three intertwining dimensions of the NGSS. Prior research has noted the complexity of the standards (Haag & Megowan, 2015; Lederman & Lederman, 2015; Pruitt, 2014; Smith & Nadelson, 2017); however, we found that teachers could conceptualize the intertwining "rope" (Krajcik et al., 2014) and discuss how they would intentionally plan for and explicitly teach the three dimensions. In some cases, teachers described lessons in which they shifted the focus of their lesson to a CCC and allowed the content to move to the "background" (i.e., elementary and high school examples of systems and systems models being the foreground focus of the lesson). Bybee's (2013) framing of foreground/background concepts was valuable for helping teachers determine how to focus lessons on multiple dimensions throughout a unit. Indeed, this framework of emphasizing one dimension at a time and allowing the other dimensions to be evident, but not explicit (i.e., backgrounded), can allow teachers to stay focused during individual lessons. As the dimension that is foregrounded shifts throughout the unit, teachers can feel confident that they are emphasizing all aspects of the NGSS without focusing on them in each lesson. The foreground/background framing of the three dimensions across a unit can be one way to reduce the overwhelming complexity of the standards, explicitly highlighting individual dimensions in each lesson, while still focusing on the intertwining rope across the unit.

The *Framework* (NRC, 2012) proposes that understanding the vertical progressions of concepts is essential to teaching science. Results from this study suggest that it was powerful for teachers to work in vertical K-12 teams, perhaps most importantly because they understood the foundations of concepts and how they become more complex throughout the grade levels. This finding aligns with the work of Gunning et al. (2020) and Trabona et al. (2019) and provides further evidence for the value of vertical teaming in NGSS PD. Indeed, in our study, elementary teachers noted that they were pushed when working with secondary teachers, and participants in all grade bands indicated that they developed a more profound understanding of the science dimensions. The opportunity to engage deeply in the learning progressions within the standards supports a greater understanding of NGSS by contextualizing grade-specific standards (Gunning et al., 2020). Penuel et al. (2014) emphasized the importance of content within the NGSS, and teachers stated that not only did they learn new content, but they viewed content in new ways. This is a vital aspect of reformed-based science teaching, as teachers begin to emphasize SEPs and CCCs in addition to DCIs to honor the intentional learning progressions across the three dimensions of NGSS (Willard, 2020). Indeed, science educators have called for a shift in how science is taught (Lee et al., 2014; NRC, 2012; Pruitt, 2014). While results from this study suggest that participants are starting to shift their thinking and instruction, they noted the need to tweak the practices and curriculum they are already using. This building on their prior practices is a crucial component of effective PD (Darling-Hammond & McLaughlin, 1995; Garet et al., 2001; NAS, 1996).

As previous studies have suggested, collegiality is vital to PD (Jeanpierre et al., 2005; Lieberman, 1995; Loucks-Horsley et al., 1998). We found that collaboration and support were critical to the success of PD on NGSS, and as did Gunning et al. (2020), specifically the opportunity for teachers to engage in discussion across K-12 grade bands. Exploring how ideas build across grade levels is a logical aspect of a deep conceptual understanding of the three dimensions.

Research has demonstrated that long-term PD is important (Garet et al., 2001; Luft, 2001; NAS, 1996; NRC, 1996; Supovitz & Turner, 2000), particularly for science teaching (Longhurst et al., 2016; Shymansky et al., 2012). We thus implemented a multi-year PD program to engage teachers authentically. This allowed them to deconstruct and understand the individual components of the NGSS and then to see the importance of putting them back together as a seamless whole. During the third year, evidence from the participants in our study suggested that this is when/where their daily classroom practice evolved to more fully embrace the core tenets of the NGSS. Collectively, this underscores the complexity of the standards and the teaching shift we are asking of our teachers. It also offers insight into the time it may take for individuals to shift their daily teaching practices substantially. In this district, science coaches will follow up with teachers and train teachers outside the program about the NGSS. While the level of intensity of the training will likely be lower, we have confidence that the science coaches will reach all teachers in the district. We hope the science coaches can model and discuss instruction that highlights an interweaving of the three dimensions (Krajcik et al., 2014) through a foreground/background approach (Bybee, 2013). Furthermore, we posit that further collaboration through PLCs within and across schools could foster a deep understanding and powerful implementation of NGSS.

We thus conclude that the unique combination of three elements of our multi-year NGSS PD program—vertical teaming, a focus on conceptual understanding, and collaborative discussion to plan for NGSS implementation, particularly in adapting curriculum—was valuable and critical. Results from this study suggest that working in collaborative teams to explore specific DCIs, SEPs, and CCCs through active science inquiry experiences allowed teachers to understand the interweaving three dimensions of the NGSS. While active learning (Darling-Hammond & McLaughlin, 1995) and collegiality (Jeanpierre et al., 2005) are vital components of PD, our program focused on fostering vertical conversations and collaboration (which included PLC work). Indeed, participants stated that these were critical aspects of understanding the dimensions of the NGSS. Similar to Gunning et al. (2020), the teachers in our study demonstrated a deeper understanding of the three dimensions of NGSS through vertical teaming and PLCs, yet our study involved a three-year PD (one year longer than that of Gunning et al.) that adapted to the needs of the teacher participants. As mentioned previously, a key element of our PD was using Bybee's (2013) conceptualization of foregrounding/backgrounding dimensions of the NGSS throughout the unit. This feature adds to the literature base by suggesting a framing of the dimensions to simplify instruction over time. The foreground/background approach may offer teachers a way to teach the three dimensions in a less complex manner, streamlining the focus of each lesson within a unit. We believe this is a powerful framing for PD and instructional planning, allowing teachers to explicitly teach each dimension, perhaps earlier in the unit, while intentionally intertwining the dimensions throughout instruction. This intertwining should also be made explicit within the unit. Finally, our study adds to the literature on PD for the NGSS. It examined the three elements and offered a way to implement the three intertwining strands across a unit by foregrounding/backgrounding individual strands in each lesson.

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Appendix A

Year Two and Year Three Focus Group Interview Protocol

Questions for Teachers Who Participated All Three Years

1. (Present participants with a list of the project components). Which component or components of the project were the most impactful on your teaching and why?
   a. Probe: Example from your teaching?
   b. **Probe based on themes from Year Two Interviews:** In what ways has Bybee's foreground/background approach affected your teaching and planning? In what ways has the format of working K-12 affected your planning and teaching? *(Year Three only)*
2. How has the project influenced your thinking, planning, and or teaching of the three dimensions of NGSS?
   a. **Probe based on themes from Year Two Interviews:** In what ways has the project influenced your: 1) understanding of the complexity of the NGSS? 2) Pedagogical growth? *(Year Three only)*
3. What supports do you still need? *(Year Two only)*
4. Of the three PLC cycles you did as a school, which do you think was most successful and why? Which was the most challenging and why? *(PLC groups only)*

Year Three Questions for New Participants

1. (Present participants with a list of the year 2 project components). Which component or components of the project were the most impactful on your teaching and why?
   a. Probe: Example from your teaching?
2. How has the project influenced your thinking, planning, and or teaching of the three dimensions of NGSS?