How Can We Move the Needle for NGSS Implementation?

Influences of a Large-Scale, Intensive Initiative on Teachers' NGSS Implementation

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The Next Generation Science Standards (NGSS; NGSS Lead States, 2013) require substantial shifts in science teaching when compared to older standards where science content was at the forefront (National Research Council [NRC], 2012). These shifts are reflective of the new vision for science education that emphasizes three-dimensional learning, centers instruction around investigating phenomena and solving problems (National Academies of Sciences, Engineering, and Medicine, 2019; NRC, 2012), and requires substantial learning and instructional change on the part of teachers (Moon et al., 2012; Windschitl & Stroupe, 2017). Kawasaki and Sandoval (2019) note that there is not much literature related to teachers modifying their instruction to meet the changed vision of science education reflected in the NGSS: “There is still a relatively thin empirical understanding of teachers’ experience...as they adapt their practices to the NGSS” (p. 2).

Multi-year science initiatives have the potential to shape teaching and learning in ways that reflect aspects of reform-oriented instruction (Sandholtz & Ringstaff, 2011, 2013; Spina et al., 2020). There have been evaluation efforts that have examined large-scale NGSS initiatives, which have uncovered systemic structures that support NGSS implementation. For example, these initiatives can bolster teachers’ understanding of the NGSS and provide them with leadership opportunities to spread science teaching best practices to others in their school or district (Nilsen, Iveland, Valcarcel, et al., 2020; Tyler, Britton, et al., 2019; Tyler, Iveland, et al., 2019; Tyler, Britton, et al., 2020).

While there is emerging research on how systems of support and other factors may affect teachers’ classroom instruction (Stiles et al., 2017), there have been very few, large-scale research projects that have studied both influences on science teaching (e.g., understanding of the NGSS and science leadership practices) and NGSS instruction (i.e., science teaching practices). Research has indicated that the duration of professional development activities, where teachers' opportunities for learning are sustained and intensive, shows promise for affecting their knowledge and instruction (Darling-Hammond et al., 2017; Desimone, 2009). Such opportunities for professional learning may equip teachers with the knowledge and skills needed to teach various science disciplines. Banilower et al. (2018) found from the National Survey of Science and Mathematics Education that only 24 percent of elementary teachers feel very well prepared to teach life science, and this percentage drops even further to 13 percent for physical science and 3 percent for engineering. Similarly, many middle school science teachers do not feel very well prepared to teach various topics within each science discipline. These recent findings support the call by other scholars to better prepare science teachers (Heller, 2012), especially in K–8. Receiving professional development with a content focus (Darling-Hammond et al., 2017; Desimone, 2009) may help teachers to not only feel prepared to teach science, but also to make improvements to their instructional practice that could benefit student learning. This study seeks to provide insight on these important and timely topics to contribute to the field of science education and standards implementation.

In order for teachers to gain experience and develop understanding of the NGSS, a large-scale initiative (referred to as the "Initiative" in this paper) was formed across eight school districts wherein a small cohort of teachers first gained foundational knowledge of the standards and then were tasked with leading others in the implementation of the NGSS in their schools and districts (see Tyler et al., 2016; Tyler, Estrella, et al., 2020 for additional details). We gathered information on the NGSS professional learning and implementation support provided by the

Initiative, then looked at how this support may have influenced teachers' NGSS-aligned instructional practices, and finally investigated factors that may have influenced teachers' instruction through participation in Initiative activities. The following research questions guided this work:

1. What do the shifts in instruction required by the NGSS look like in practice?
2. How did variations in…

a. teachers' duration of participation in a multi-year, sustained, and intensive professional learning experience	**and**	**b.** their role in such an initiative

affect

x. their understanding of the NGSS,	**y.** their science leadership practices,	**and**	**z.** their science teaching practices?

Theoretical Framework

Systems of NGSS Support

Implementation research states that contexts and conditions can and often do affect the enactment of innovations and that "improving education requires processes for changing individuals, organizations, and systems" (Century & Cassata, 2016, p. 172). Yet, researchers have found that most districts do *not* have systemic structures to support instructional improvement, even in the heavily emphasized subjects of math and ELA (Cohen et al., 2018; Lavigne & Good, 2019).

Within the Initiative, we consider each district as its own system, with smaller, nested systems within it (e.g., the school and classroom; Bronfenbrenner, 1979). Within the classroom is the learner, which we argue will not only include the student, but also the teacher (Lieberman, 1995). We acknowledge that these systems are not cleanly nested within one another, and networks and system drivers between, across, or outside of them may affect learners within

(Lave & Wenger, 1991; Stiles et al., 2017; Wenger, 1998; Wilson, 1993). We intend to view all learners in this system, particularly the teacher in this study, utilizing a situated perspective (Lave, 1988; Peressini et al., 2004).

Effective Professional Development

We examined the Initiative and its influences by drawing on the five core features of professional development that Desimone (2009) established to guide education researchers in studying the effects of professional development. These core features include content focus, active learning, coherence, duration, and collective participation. Desimone goes on to attest that these features of effective professional development are part of a larger theory of action that leads to increases in teacher knowledge and skills, changes in their attitudes and beliefs, changes to their instruction, and finally to increased student learning. Her model also includes context factors that may influence all of these components along the way. The Initiative sought to attend to each of these core features, while also attending to the context factors within the larger district systems and their potential influence on standards implementation.

One major shift that can happen when transitioning from more traditional science instruction to science instruction aligned with the NGSS is a cultural shift (Vigeant, 2018). This cultural shift extends beyond classroom instruction, and into the school system itself. The Initiative followed multiple steps to facilitate such a shift in school culture, including providing professional learning to help teachers first understand the NGSS and the shifts required to implement these standards, opportunities to gain leadership skills and help other teachers transition to the NGSS, and a structure that encouraged sustainability of the new “NGSS culture” in the school system (Tyler & DiRanna, 2018).

This focus on school culture and the different actors within it enabled the Initiative to develop a community of practice aligned with situated views of learning. In a situated theory of learning, learning is conceptualized as more than passively receiving information with facts from another individual (Lave & Wenger, 1991). Rather, learning is viewed as engaging in authentic practices, moving from being a peripheral participant to a fully active member of a community of practice (Brown et al., 1989; Greeno, 2006; Putnam & Borko, 2000). Learning is highly dependent on context, situated in social settings and developed through interactions with materials and people over time (Lave & Wenger, 1991; Putnam & Borko, 2000).

Further, a community of practice marks a shift away from previous models of professional development that sought to impart knowledge and skills onto a teacher. This is in line with not only the collective participation feature of professional development described by Desimone (2009), but also the inclusion of *context* in her framework that inevitably influences the entire district system during implementation initiatives.

Teacher Leadership

Since the Initiative featured teacher leadership training and responsibilities as a major component of their professional development across all districts, our research examined this topic. Teacher leadership is an additional area that affects the successful implementation of standards. Drawing on prior work on teacher leadership (Wenner & Campbell, 2017; York-Barr & Duke, 2004), this study intends to build on the literature around teacher leadership specific to science and the implementation of the NGSS (e.g., Bae et al., 2016; Cheung et al., 2018).

For example, Bae et al. (2016) identified three types of teacher leaders that emerged from their analysis: "(1) instructional innovator, (2) professional learning (PL) leader, and (3) administrative teacher leader" (p. 916). Specifically, instructional innovators are recognized as leaders in science teaching and learning and their leadership work centers on students and the classroom. Professional learning leaders have expertise in facilitation and are adept at working with adult learners. They exhibit leadership at the school site, district, and national levels and the target audience of their leadership work is their colleagues. Administrative teacher leaders are influencers within their school sites and districts and participate in making decisions affecting these systems. They are involved in building networks of stakeholders and breaking down hierarchies to engage different actors within the systems. The target audience of their leadership work is system-level actors, including administrators, policy-makers, and other teachers, with the purpose of fostering "a shared leadership commitment to science education" (Bae et al., 2016, p. 925). In this study, we wanted to see whether Bae et al.'s (2016) typology of teacher leadership could be confirmed in our data.

NGSS Enactment Framework

Our definition of NGSS enactment will be guided by the research framework developed by Iveland et al. (2019; Figure 1). This framework was developed by reviewing California policy documents (e.g., California Department of Education [CDE], 2017) and research and practitioner publications on the NGSS and related topics (e.g., Bang et al., 2017; Berland et al., 2016; Krajcik et al., 2016; Miller et al., 2018; Schwarz et al., 2017). Observations in K–8 science classrooms, PL events, and interviews with teachers, including some Initiative participants, over the course of several years were also used to further elaborate this framework.

This framework identified six key aspects of NGSS to serve as foci in studying classroom enactment of the NGSS: 3-dimensional learning, phenomena-based learning, engineering, epistemic agency, equity, and coherence. Researchers are finding that these aspects of the NGSS are likely nested within and across one another, with the inside aspects being the most critical in enacting the NGSS. Through incorporating more outer “layers” (i.e., phenomena, engineering, epistemic agency, and equity), the robustness of NGSS enactment may increase and be more closely aligned with the standards’ full vision for science instruction (Iveland et al., 2019).

Design and Methods

Participants

The Initiative spanned six school years from 2013–2020 and provided professional learning and implementation support to eight school districts across California. They targeted a diverse group of students across the eight California school districts. All but one district in the Initiative had a majority of students who were underrepresented minorities and eligible for free and reduced-price meals and included more English Learners than California’s state average (18.63%; CDE, 2020). Furthermore, the districts were located in different geographic areas of the state and in different sized communities (i.e., urban, suburban, and rural).

To accommodate the diverse populations and their needs, the Initiative created a common organizational structure within and across participating districts to support NGSS implementation at multiple levels (e.g., Regional Directors across districts, Project Directors at the district level, Site Administrators at the school level). For the purposes of this paper, we are looking at the district, school, and classroom levels. Participants in this study were teachers with leadership roles, though we acknowledge that there are other important actors in the district system (administrators, parents, community).

Initiative Activities

Teachers took part in a community of practice in their district, called the Core Leadership Team, to collectively shape and lead NGSS implementation. Teachers were recruited in two phases. First, six to ten teachers in each district joined the Core Leadership Team to plan and lead NGSS implementation. Teachers in this group, known as *Core Teacher Leaders*, had intensive professional learning with the understanding that they would have a significant role in sharing what they learned with other teachers in their district. These Core Leadership Teams also included three to five administrators, known as *Core Administrators*, who typically were site administrators at either the elementary and middle school levels, and sometimes central office staff. Each district's Core Leadership Team worked with that respective district's *Project Director* (the assigned staff member dedicated to NGSS implementation for the Initiative) in planning and carrying out NGSS implementation in the district, including its sustainability.

The summer before the second year of the Initiative, each district recruited between 30 and 70 additional teachers, called *Teacher Leaders,* who would also play an important role in spreading NGSS learnings to their colleagues. *Teacher Leaders* received less rigorous professional learning than *Core Teacher Leaders*—approximately nine days per year compared to the 21 days *Core Teacher Leaders* received—but were still integral to district NGSS implementation and had substantial leadership opportunities. We will refer to the collective group of both *Teacher Leaders* and *Core Teacher Leaders* as *teacher leaders* (lowercase).

In addition to receiving professional learning about the standards themselves and how to implement them in their own science instruction, teacher leaders participated in team building activities to foster cooperation and establish a collaborative culture within their district leadership teams (Garmston & Wellman, 1999). Before leading on their own, teachers planned and presented in pairs to develop feelings of competence and gain experience. They also received training on how to be change agents in their districts and interact with teachers who may be reluctant to change their instruction (see Tyler, Britton, et al., 2019 for additional information).

Data Collection

For this study, all observation data were collected from 2016 to 2020, while survey data were collected at the end of each school year throughout the Initiative from Spring 2014 to 2020. Below, we discuss details of each form of data collection used in this study.

Observations

We directly observed 53 case study teacher lessons over the duration of the Initiative. Specifically, case study teachers were a small number of teacher leaders who provided the study with a look at NGSS implementation at the teacher and classroom level in Years 3–6 of the Initiative. Case study teachers were nominated by district Project Directors as those who were making some of the most substantial changes in their NGSS teaching. Each of these teachers were observed teaching an NGSS lesson for one or two class periods per year.

Surveys

Each summer, Teacher Leaders in each district were surveyed about their thoughts and experiences on the previous school year. The first survey was the annual leadership survey, which asked teacher leaders about their leadership and the leadership of others during the prior school year. The second survey completed by all teacher leaders in the Initiative was the Classroom Science Teaching Survey. This survey asked teachers about their science teaching practices and their experiences during the previous school year. Selected survey questions that were examined for this paper include: Understanding of the shifts in pedagogy required to teach the NGSS; understanding of the structure of NGSS; understanding of how to help teachers implement the NGSS; and teacher's Initiative role. Between 65 and 75 Core Teacher Leaders annually completed the Teacher Leadership Survey between 2013–14 and 2017–18, representing a response rate ranging from 81 to 100 percent; 330–447 Teacher Leaders completed the Teacher Leadership Survey between 2014–15 and 2017–18, representing a response rate ranging from 69 to 88 percent; and 252–435 teacher leaders completed the Classroom Science Teaching Survey between 2015–16 and 2019–20, representing a response rate ranging from 51 to 88 percent. The high survey response rates suggest that this paper's discussion of survey data reflects the responses of almost all teacher leaders in the Initiative, i.e., there is a low threat of response bias.

Data Analysis

Each data analysis was conducted to understand the components, implementation, and outcomes of the Initiative. As such, each analysis was a case study of the larger Initiative. In order to understand the parts of the district system and how the parts contributed to the whole system, we did a deep dive to look at the support that teachers received and provided to others. We pursued different lines of inquiry and then triangulated the findings to draw conclusions about NGSS support provided by the Initiative. For example, we focused in on the teacher professional development experience according to Desimone's (2009) core features, in particular content focus (e.g., by examining their understanding of NGSS) and duration. We also examined how teachers were implementing what they learned in their classroom instruction and present one exemplary teaching example aligned with the vision for K–12 science education. Taken together, the results reveal how the Initiative engaged, supported, and influenced teacher leaders.

Observations

We examined what enactment of the NGSS looked like in science classrooms following the NGSS enactment framework (Iveland et al., 2019) which guided our analysis of observations. Case study teacher observations were categorized based on the presence and robustness of each of the six key features of NGSS enactment: three-dimensional learning, phenomena-based learning, engineering, epistemic agency, equity, and coherence. Similar to Miller et al. (2018), we used vignettes of instruction to provide a rich description of what NGSS enactment looked like in one science classroom. Specifically, the use of vignettes helps to uncover how features of the NGSS are taken up, including through engagement in the science and engineering practices.

Surveys

A variety of survey question responses were examined, in particular questions about teacher leaders' understanding of aspects of the NGSS, their implementation of these aspects in their classroom instruction, and their science leadership practices.

Survey data were analyzed in phases. In the first phase, we analyzed both mean values and percentages by response option for trends across the years of the Initiative for selected variables of teacher leaders' understanding and implementation of the NGSS. Specifically, we examined teacher leaders':

- Understanding of the Science and Engineering Practices (SEPs) within NGSS and how they are used during instruction
- Understanding of the Crosscutting Concepts (CCCs) within NGSS and how they are used in instruction
- Understanding of NGSS engineering design and how students engage in it
- Understanding of the use of phenomena to drive science instruction

- Frequency of incorporating NGSS Science and Engineering Practices (SEPs) during instruction
- Frequency of incorporating NGSS Crosscutting Concepts (CCCs) during instruction
- Frequency of having students engage in NGSS engineering design
- Frequency of using phenomena to frame instruction

A composite variable was created for the two dimensions of the NGSS (i.e., SEPs and CCCs) of the selected variables above to represent three-dimensional NGSS understanding and enactment. Disciplinary core ideas (DCIs) were not included because it was assumed that teachers will be incorporating the content as this was required by the standards prior to the NGSS and would not constitute and substantial change in their understanding or instruction. In addition, data for these variables were disaggregated by the teachers' role in the Initiative to see if there were differences between the Core Teacher Leaders' and the Teacher Leaders' responses.

In the second phase, we examined teacher leaders' responses to questions about their science leadership practices. In order to understand influences on science leadership practices, we conducted three types of analyses. First, we analyzed the survey responses to determine the existence of underlying factors behind teacher leaders' responses about their science leadership practices. Specifically, 15 survey items were examined for their factorability. An exploratory factor analysis (EFA) was conducted on the 2017–18 data set (n = 368) using R (The R Foundation, 2021). Fit indices did not show goodness of fit, which warranted a continued analysis of this model through a subsequent confirmatory factor analysis (CFA), conducted on a data set from the prior year (n = 512) and using the model derived from the EFA. The final CFA model included 10 of the original 15 survey items (Nilsen, Valcarcel, et al., 2020).

Second, we analyzed the survey responses to investigate whether teachers who rated themselves differently on questions relating to the NGSS and their role in the Initiative also rated themselves differently on questions relating to leadership. Data were analyzed using Kruskal-Wallis H tests (Kruskal & Wallis, 1952) to examine potential differences between groups. Post hoc pairwise comparisons were performed using Dunn's procedure due to the Likert scale questions being ordinal, rather than on an interval or ratio scale (Sawilowsky, 1990). This analysis helps to answer the second research question about how teachers' role in the Initiative affects science leadership practices and relates to the development of understanding through participation in professional development with a content focus (Desimone, 2009).

Third, we analyzed the survey responses to uncover how frequently teacher leaders reported that they engaged in science leadership practices. We ran descriptive statistics on the data to generate means for both the Teacher Leader and Core Teacher Leader groups. We examined trends within groups for average responses to the 10 survey items generated from the final CFA model, as well as looked at differences in group means for each item. These analyses reveal which group engaged in science leadership practices more often on average, which practices were reported to have occurred more frequently, and group differences in science leadership that may be attributable to differential amounts of professional learning and implementation support provided by the Initiative.

This final analysis was a deep dive that examined the relationship between Initiative role and science leadership practices. Whereas the Kruskal-Wallis analyses statistically reveal whether there are group differences in leadership according to role in the Initiative and understanding of the NGSS, the descriptive analyses further disclose the extent to which each teacher leader group engaged in different amounts and types of leadership.

Results

To answer our first research question about what NGSS instruction looks like in practice, we did a deep dive into observation data from case study teachers. To answer our second research question about the ways in which the Initiative and duration of participation influenced teachers' understanding of the NGSS, leadership, and science teaching practices, we looked at survey responses across all teacher leaders. Findings from these data not only highlight the influences of the Initiative on teacher leaders as a whole, but also provide specific examples of what NGSS-aligned instruction can look like in practice. An illustrative vignette is provided to highlight how one teacher's instruction reflected reform-oriented practices aligned with the NGSS. Results compiled across teacher data sources provide an indication of the Initiative's efforts in supporting district systems' NGSS implementation.

Observed Instructional Changes

Across our data set, we were guided by our NGSS enactment framework to identify each focal aspect of the NGSS and our analysis revealed that teachers enacted the NGSS to different extents. From this analysis, an illustrative vignette from one teacher's classroom observations was selected. This teacher received professional learning from the Initiative and implemented a lesson that incorporated key features of the NGSS. This example was chosen to illuminate what NGSS instruction looks like in practice.

The following lesson, taught by a grade 8 teacher, addressed physical science content. This lesson, observed over two days, is part of a multi-lesson learning sequence. After the lesson is presented and discussed, features of the NGSS in the lesson are described.

Understanding White Sharks

When she first introduced it weeks ago, Ms. Gill (pseudonym) grounded the multi-week white shark unit (NGSS Early Implementers, 2020) in an engaging and locally relevant anchor phenomenon: a map showing an increase in shark encounters in recent years, especially in Southern California, where the class was held. The teacher used this phenomenon to kick off a series of activities that would result in students gaining a deep understanding of many aspects of the phenomenon, including how scientists are researching it.

Through some initial research and investigation into what they wondered about white shark sightings and attacks in the state, students had already begun learning about how scientists research and monitor white sharks and what kinds of technology they use to do this. On the day of the classroom observation, the lesson kicked off with a video showing scientists attempting to attach satellite tracking tags to white sharks' fins to study their movement and behavior. The video further explained that certain parts of a shark must be avoided when attaching a tracker, but the scientists were having trouble seeing the sharks clearly when looking down into the water from above. Students then discussed this investigative phenomenon: that researchers have a hard time estimating the precise position and size of a white shark under the water.

Students discussed their ideas about the scientists' challenge, and the class used an inflatable shark in the classroom to discuss where on the shark they thought scientists should attach the tracker. Then Ms. Gill asked them to draw or write a model of their thinking about the challenge, with "concise bullets describing what you think light does" when it hits water, "like what you saw in the video of scientists tagging the sharks." She gave students a choice on what this model would show: "You guys can decide what you do with this model. You just need to make your thinking visible."

Next, Ms. Gill set up a series of lab stations in the classroom that provided materials for students to conduct hands-on investigations into different properties of light. At one station, students could use a long dowel to simulate attaching a tracker to a small, submerged shark toy. They remarked that the activity was "pretty hard to do." Students found that they often missed the target on the shark's body that they had agreed was the best location for the tracker because "[the light interacting with the water] makes it look like [the dowel] is bending."

The following day, in small groups, students used evidence from these investigations, along with their prior knowledge, to complete two group assignments: 1) a collaborative explanation using Claim, Evidence, Reasoning (CER) statements and 2) a model. A full description of the observation with pictures of student work are included in an evaluation report about the Initiative (Nilsen, Iveland, Tyler, et al., 2020). In both assignments, students worked in teams to express what they thought was happening that made it difficult to tag the sharks when viewing them from above the water.

Connections to the NGSS Enactment Framework.

Ms. Gill's instruction incorporated five key features of NGSS enactment: phenomena-based learning, coherence, epistemic agency, three-dimensional learning, and equity. Ms. Gill used an *anchor phenomenon* (the increase in shark encounters in recent years) to engage students' interest and encourage them to think like scientists. Because the phenomenon was locally relevant, most or all of the students likely had some prior knowledge about it, providing a base on which new learning could build. Subsequent lessons were linked to this anchor phenomenon and provided students with a larger framework for learning that made the lessons more meaningful. Ms. Gill's use of an anchor phenomenon in her unit and lessons that enabled investigation of the anchor phenomenon provided *coherence*, where students were able to build on their initial ideas using evidence gathered from their investigations to make sense of the anchor phenomenon. Ms. Gill provided her students with *epistemic agency*, where they had choice of what to include in their model to make their thinking visible. In addition, students were active participants in class, pursuing their own questions and project ideas. *Three-dimensional instruction* is evident in Ms. Gill's shark unit. Students developed and used models and carried out investigations (two science and engineering practices), utilized crosscutting concepts like cause and effect, and explored science content across multiple domains (physical, life, and earth science).

There are also aspects of instructional practice that promote access and *equity* in this vignette: Ms. Gill regularly referred to visuals and models around her classroom, including an inflatable shark model in her room that was used to make the discussion about shark anatomy more concrete and relatable for all students. Students worked through the stations on properties of light in small groups, enabling student-to-student discourse in which they could ask and answer questions of each other. They learned about properties of light through hands-on investigations that enabled them to experiment and manipulate variables of their choosing. Finally, the topic of shark encounters was locally relevant and likely familiar and personally meaningful to most, if not all, students because they live in a beach community where residents are generally aware of these dangers. They had a reason to engage in the lessons because they knew that it would be helpful for them to understand how and why light interacts with water when trying to study shark behavior, which would influence them being able to figure out why there had been more shark encounters recently.

NGSS Understanding

Teacher leaders were surveyed about their understanding of key aspects of the NGSS at the end of the 2014–2015 through 2019–2020 school years. An examination of mean values and changes over time revealed two distinct patterns across the years of the Initiative – one showed distinct increases for understanding of the NGSS for Teacher Leaders specifically, and another showed differences in NGSS understandings of the SEPs and CCCs over time when comparing Core Teacher Leaders' and Teacher Leaders' responses.

First, Teacher Leaders' average understanding increased over time for each of the key aspects of the NGSS (Figure 2). Specifically, there were slight, but steady increases in Teacher Leaders' mean levels of understanding of the use of phenomena to drive science instruction and their understanding of NGSS engineering design and how students engage in it.

Teacher Leaders were asked about their understanding of the Science and Engineering Practices (SEPs) and Crosscutting Concepts (CCCs) within NGSS for an additional two years at the very beginning of the Initiative.

Results indicate that on average they made substantial gains in their understanding of these two dimensions of the NGSS during this time (i.e., from a mean value of 2 in 2014–2015 to a mean value of 3 in 2016–2017, corresponding to response options of "Poorly" and "Fairly well," respectively). The magnitude of the gains from the 2016–2017 through 2019–2020 school years was similar to the increases that teachers reported for the phenomena and engineering design questions. This trend suggests that participation in the Initiative had an influence on Teacher Leaders' understanding of aspects of the NGSS and that sustained engagement in the Initiative's professional learning sessions over time and reception of implementation support may be one factor that influenced their NGSS understanding.

The second pattern we noticed in the survey data was around teacher leaders' responses to questions about their understanding of the SEPs and CCCs. By the end of the Initiative, Teacher Leaders' mean levels of understanding of these two NGSS dimensions roughly equaled the understanding of the Core Teacher Leaders (Figure 3). This trend may indicate that the supports provided over time by the Initiative, including support provided to Teacher Leaders by the Core Teacher Leaders, influenced these participants over the long-term resulting in both groups of teacher leaders having gained substantial understanding of key elements of the NGSS.

This finding may also indicate that teachers with science leadership roles are better positioned to gain a deeper understanding of the NGSS, since they must help their colleagues understand and implement it. Though Core Teacher Leaders received more professional learning opportunities and implementation support in the initial years of the Initiative, their joint, district-wide efforts with Teacher Leaders to help implement the NGSS widely across their school and district systems may have helped equalize their depth of NGSS knowledge.

Teacher Leadership

From our factor analyses of the set of survey questions, we found that teacher leaders' opportunities for leadership or perceptions of the types of leadership they can engage in were distinct between those existing at their school sites and those within their larger district (Nilsen, Valcarcel, et al., 2020). These findings indicate that teacher leaders may demonstrate leadership in different amounts and/or in different situations depending on whether they are at a school or a district-level function. It could also be that the situations at the different levels lend themselves to different amounts of leadership (e.g., more opportunities to present at school professional learning communities). From the Kruskal-Wallis H test analyses and post hoc pairwise comparisons, we found that there were relationships between teachers' understanding of NGSS and their science leadership practices, as well as between their Initiative role and these practices (Nilsen, Iveland, Valcarcel, et al., 2020). From the descriptive analyses, we found that Core Teacher Leaders on average reported that they engaged in science leadership practices more often than Teacher Leaders (Table 1). For all of the practices, Core Teacher Leaders "occasionally" to "frequently" engaged in them. However, differences in means between these groups were the greatest at the district level. Core Teacher Leaders more frequently performed district-level science leadership practices than Teacher Leaders. This suggests that preparation for leadership and more opportunities given to Core Teacher Leaders may have influenced their frequency of engaging in leadership practices.

Science Teaching Practices

From our analyses of teacher leaders' science teaching practices, we found that duration of participation in the Initiative had an influence on their reported instruction. Survey responses showed that teacher leaders who were involved in the Initiative longer had an increased frequency of incorporating key NGSS features in their science instruction. When looking at teacher leaders' implementation of the NGSS by the end of the Initiative (the 2019–20 school year), survey results indicated that, overall, those with more years of experience in the Initiative as either Teacher Leaders or Core Teacher Leaders reported incorporating phenomena, engineering, the SEPs, and the CCCs into their science instruction slightly more with each additional year where they served in a teacher leader capacity in the Initiative (Figure 4). These findings point to the value of not only providing intensive professional learning to teachers implementing the NGSS, but also leadership opportunities over an extended period of time.

Discussion

This study contributes to the literature by determining the influences of a large-scale, multi-year NGSS initiative on teachers' understanding and implementation of the new science standards and leadership in helping other teachers to implement them, and provides a detailed, illustrative qualitative example of naturalistic NGSS instruction that incorporates key features of the standards. More specifically, the study results have implications for developing and sustaining initiatives for (1) supporting teachers' NGSS understanding and implementation through intensive professional development opportunities, (2) providing leadership opportunities to teachers to deepen their own NGSS understanding and practice and to help others do the same, (3) creating a system of NGSS implementation that includes communities of practice with teacher leaders as change agents for promoting widespread, high-quality science instruction, and (4) creating opportunities for the education system to implement changes towards NGSS implementation over a prolonged period of time.

While there is some work focused on NGSS professional development (e.g., Haag & Megowan, 2015; Hestness et al., 2014), there has been little research done on initiatives at this large scale, or which show multi-year, longitudinal influences of such professional development on teachers' NGSS understanding and instructional practice. The influences of the Initiative in this study highlighted how when provided with sustained, intensive NGSS professional learning, teachers will demonstrate growth in their understanding of the NGSS over the long-term.

Further, our findings on the influences of providing leadership opportunities to teachers in such a large NGSS initiative are promising and add to the growing body of literature on science teacher leadership (e.g., Bae et al., 2016; Cheung et al., 2018; Wenner & Campbell, 2017; York-Barr & Duke, 2004). We found that teachers indicated having a deeper understanding of the NGSS when they had more leadership opportunities (i.e., served as a Core Teacher Leader) and incorporated the NGSS in their instruction more often the longer they participated in a leadership capacity within the Initiative (i.e., served as either a Teacher Leader or Core Teacher Leader).

We also identified two types of teacher leadership that teacher leaders tended to indicate they participated in throughout the Initiative, *District* and *School*. These factors identified in the survey responses may be similar to the professional learning and administrative teacher leadership categories identified by Bae et al. (2016). Teachers answered survey questions about formally presenting about NGSS implementation to others and playing an important role in building a professional community devoted to the vision of NGSS, which seem to relate to the roles and responsibilities of professional learning leaders and administrative teacher leaders, respectively. However, within both school sites and districts, teachers can display professional learning and administrative leadership. Indeed, Bae et al. (2016) point out that there are correlations between their types of teacher leadership, suggesting that teachers are not purely categorized into one type of leader or the other.

In addition, our study has the implication that NGSS understanding and leadership are related to instruction, as Core Teacher Leaders reported understanding more on average and engaging in leadership practices more often than Teacher Leaders. Taken together with the fact that many Core Teacher Leaders have been involved in the Initiative longer than Teacher Leaders and that duration of Initiative participation is connected to the frequency of teachers' incorporation of NGSS aspects in their science instruction, it is likely that understanding and leadership are factors that affect instructional practice. Thus, study findings corroborate

Desimone's (2009) research on the effects of professional development, where duration of participation and a content focus of the trainings can affect teachers' knowledge and practice.

These findings further reinforce the need for science teacher professional development, especially when implementing new standards such as the NGSS, to be robust, sustained, and include teachers as critical change agents within their school or district system. By providing opportunities and creating systems where teachers are empowered to extend their knowledge and practice outside of just their classroom, standards implementation initiatives or other mechanisms for instructional change will benefit from teachers' leadership capacity to influence not only other teachers within their school or district system, but also administrators and others who undoubtedly influence such implementation initiatives and classroom instruction.

Last, our illustrative vignette that highlights several key features of the NGSS in practice provides the field with a rich example of how the NGSS are enacted in a classroom with a highly knowledgeable teacher. The analysis and results suggest ways to improve classroom teaching and learning to be more in line with the exemplar provided in the vignette.

District and school leadership must ensure that after teachers are trained, demonstrate an understanding of the standards, and express a willingness to implement them in their instruction, they are allowed to do so with minimal interference. Further, teachers should not only be included in the conversation around important topics like curriculum adoption (Nilsen, Tyler, et al., 2020), but they should also serve as important decision makers in these processes.

Study Limitations

Our teacher surveys relied on teacher self-reported data, which inherently contains response bias: respondents might answer with what they think you want to hear, rather than with how they actually feel or what they actually did (Howard & Dailey, 1979). For example, because much of our data collection asked about topics specific to the NGSS, some teachers who may not have been as familiar or comfortable with the NGSS may have responded more favorably to the survey questions at the beginning of their involvement in the Initiative, which allowed little room for growth in subsequent years: indicating a potential ceiling effect (Ettema & Kline, 1977; Joyce et al., 1999; Judson, 2012; Trudel et al., 2017). This may have been true of Core Teacher Leaders' reported understanding of the NGSS, which peaked during the 2017–18 school year and then dipped in the final two years of the Initiative (see Figure 3).

We also did not receive a consistent amount of data for participating teachers due to scheduling when they joined the study, and teacher turnover. Furthermore, our survey analyses examined aggregated data at each timepoint (e.g., spring of each school year), rather than tracking individual teachers' progress in their understanding of the NGSS, leadership practices, and science instruction. Thus, although the results are indicative of how teachers as a group were feeling and what they were doing at a particular point in time, they do not reflect changes of teachers as individuals, nor do the results signal attrition or the addition of new teacher leaders after the Initiative started.

Other limitations of this study include that teachers received varying amounts and types of support once the Initiative transitioned in Years 5 and 6 from a centralized to a district-led implementation model, and that teachers did not receive explicit instruction on all aspects of the theoretical NGSS enactment framework (which was used to examine how well they enacted the standards). Further, observation data were only collected from case study teachers, who were not representative of the larger sample of teacher leaders. These teachers were nominated by district leaders because of their quality NGSS teaching, which likely influenced the qualitative data collected in this study. In addition, because teachers sometimes did not enact the NGSS thoroughly despite being recipients of substantial NGSS support there may be additional constraints at play, such as lack of access to quality curriculum or personal barriers related to values and beliefs that hindered their implementation, which are beyond the scope of this study.

Future Research

In the future, we hope to build on this research by looking at administrator data that were collected over the course of the Initiative. In particular, administrator surveys ask about their perceptions of the influence of professional learning experiences on their understanding of the NGSS and their support of teachers teaching the NGSS from the 2013–14 school year through the end of the Initiative in 2020. Because administrators are supports and can also be catalysts for change at their sites, reviewing a dataset that includes them would help to provide a fuller picture of the entire district system, and would shed light on how the system (and the parts within the system) changed over time as a result of involvement in the Initiative.

In addition, we would like to investigate the possible influence of teacher beliefs on science leadership practices and instruction. It could be that teachers who adopted reform-oriented practices are the ones more readily integrating teaching strategies aligned to the NGSS and more involved in science leadership at their site and/or district. Although our analyses revealed a relationship between NGSS understanding and type of leadership role, we did not control for possible mediating factors related to beliefs and values. For example, teachers who were chosen for the Core Leadership Team may have expressed interest in this role due to the alignment of the NGSS with their orientation to teaching, so their beliefs and values may have influenced the makeup of this teacher group, and the tendencies of this group to engage in professional development, leadership, and instructional innovations that are in line with the NGSS. Similarly, having reform-oriented beliefs may have had an influence on science instruction as these teachers may have already been engaging in teaching practices that reflect the vision of science education described in the *Framework* so they were *building* upon their practice as opposed to *learning* an entirely new way of teaching. Being able to investigate the influences of reform-oriented instructional practices on NGSS implementation builds on prior work (Spina et al., 2020) and would contribute new information on membership in the community of practice.

Lastly, we would like to investigate longitudinally how long these kinds of interventions and/or support may affect teachers' understanding, leadership, and instruction, and how long changes in teachers' instructional practices may persist after the supports are removed (Sandholtz & Ringstaff, 2016). We are continuing to work with these districts in order to determine the sustainability of the capacity built over the course of the Initiative.

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Tables and Figures

Table 1

Means of Teachers' Science Leadership Practices by Initiative Role and by School or District Level

	Means		**Difference in Means**	**Sample Size (*n*)**	
Survey Question	Teacher Leader	Core Teacher Leader		Teacher Leader	Core Teacher Leader
Shared instructional philosophies, strategies, and/or ideas related to NGSS with colleagues in your SCHOOL	3.22	3.44	0.22	307	63
Met with other teachers in your SCHOOL to reflect on their practice to help them better meet the vision of NGSS	2.82	3.15	0.33	307	62
Played an important role in your SCHOOL in building a professional community devoted to the vision of NGSS	2.75	3.24	0.49	304	63
Shared challenges associated with NGSS implementation with colleagues in your SCHOOL	3.12	3.24	0.12	307	63
Helped establish a safe environment to discuss opinions, beliefs, and knowledge related to NGSS in your SCHOOL	3.03	3.41	0.38	307	63
Shared instructional philosophies, strategies, and/or ideas related to NGSS with colleagues in your DISTRICT	2.72	3.17	0.45	305	63
Met with other teachers in your DISTRICT (outside of your school) to reflect on their practice to help them better meet the vision of NGSS	2.56	3.06	0.50	303	63
Played an important role in your DISTRICT in building a professional community devoted to the vision of NGSS	2.34	3.08	0.74	305	63
Shared challenges associated with NGSS implementation with colleagues in your DISTRICT	2.64	3.08	0.44	305	63
Helped establish a safe environment to discuss opinions, beliefs, and knowledge related to NGSS in your DISTRICT	2.56	3.02	0.46	304	63

Note. All survey items have these response values: 1 = Never, 2 = Seldom, 3 = Occasionally, and 4 = Frequently.

Figure 1

NGSS Enactment Framework (Iveland et al., 2019)

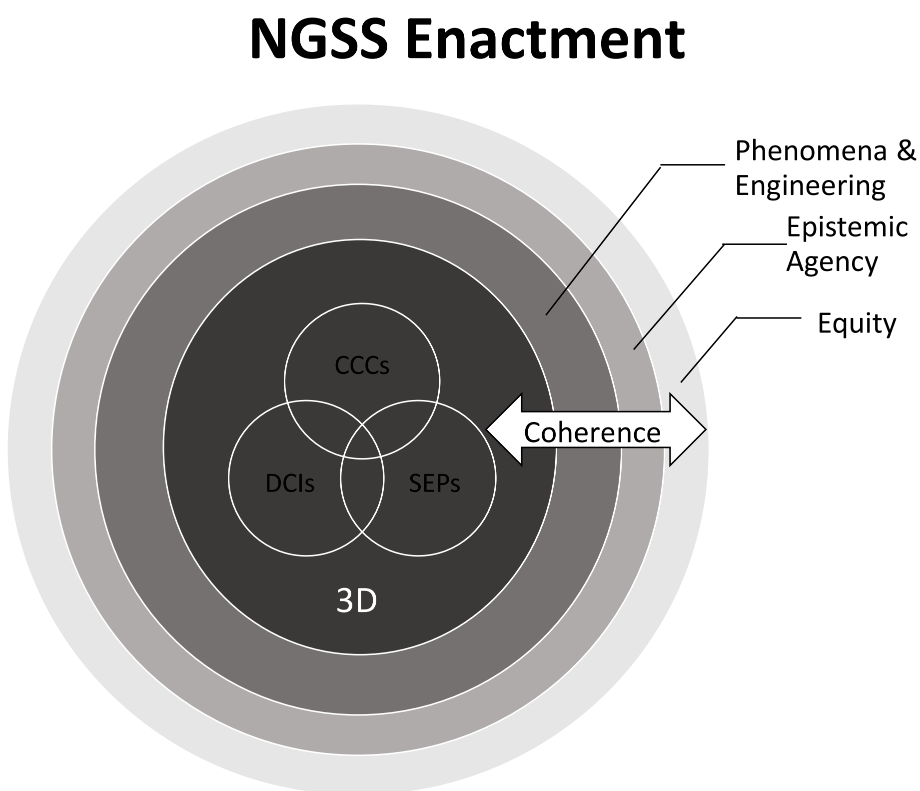


Figure 2

Teacher Leaders' Understanding of Key NGSS Features Over Time

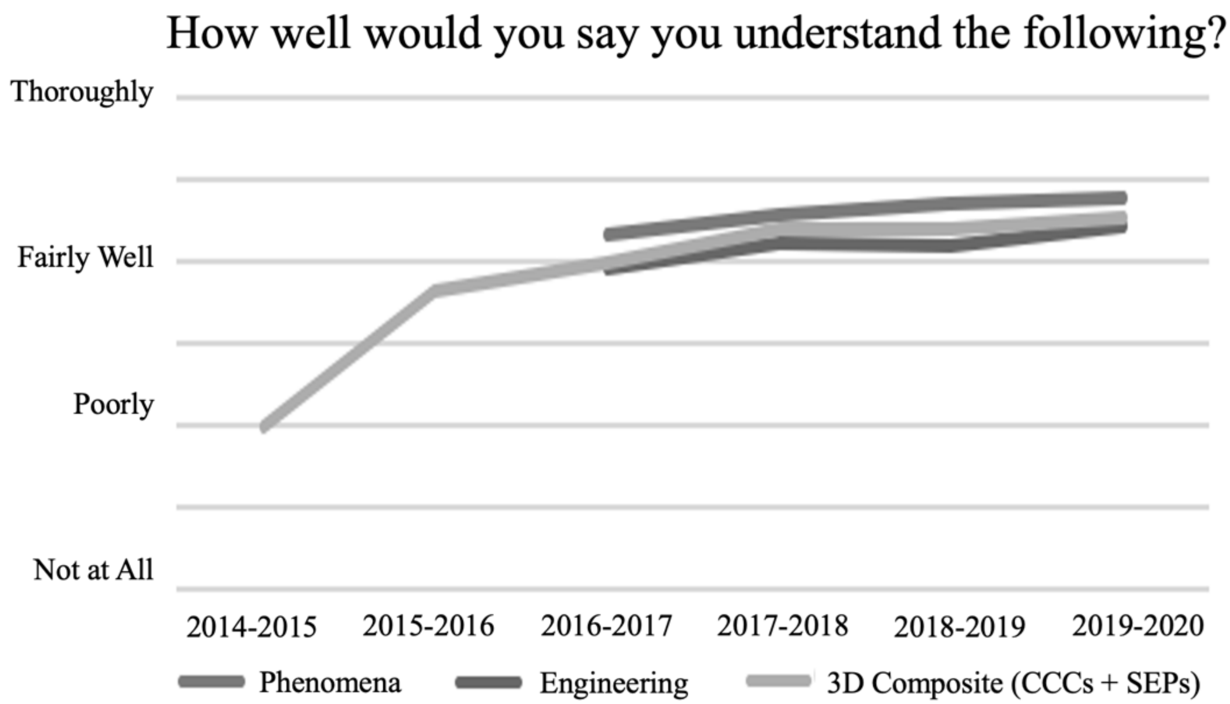


Figure 3

Understanding of SEPs and CCCs Over Time by Initiative Role

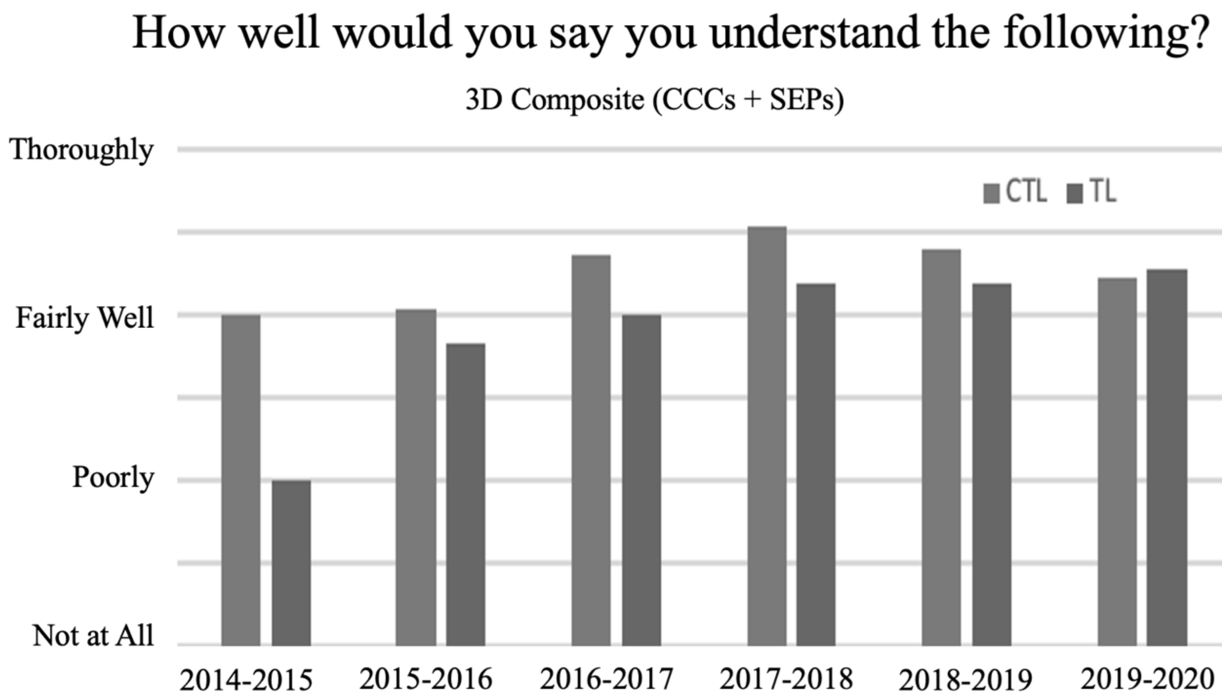
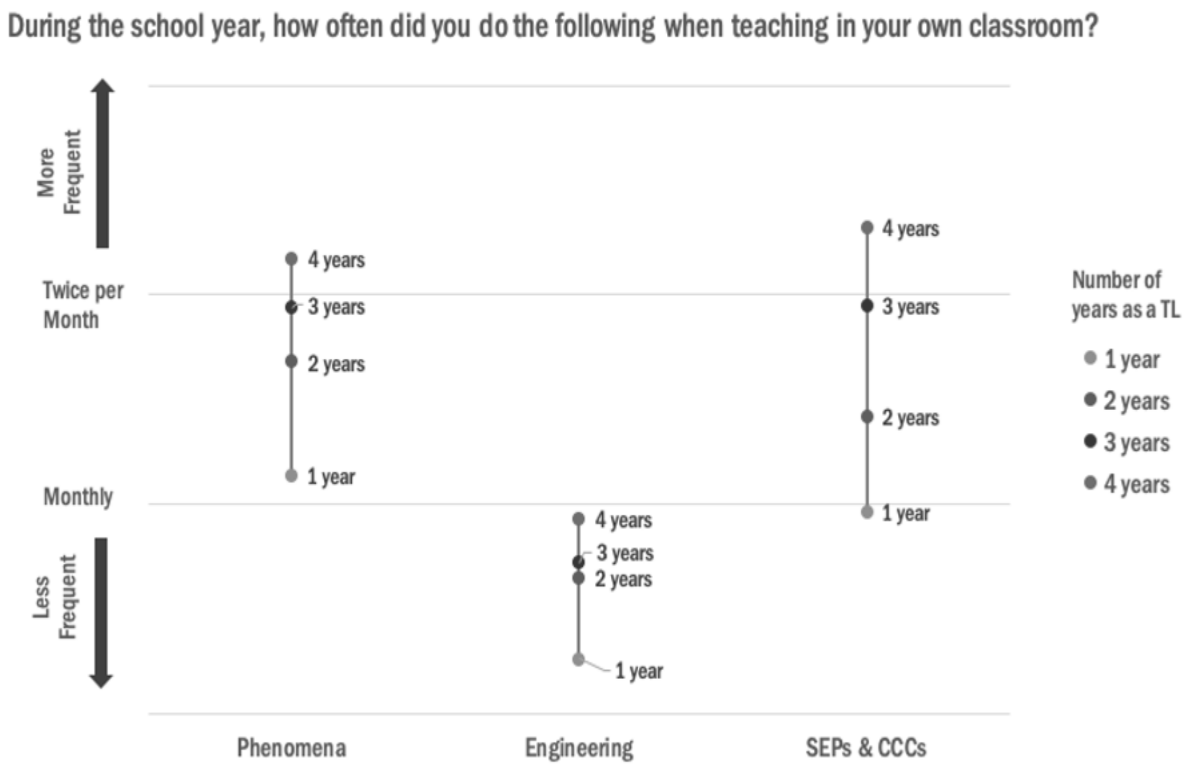


Figure 4

Implementation of Key NGSS Features in 2018–19 by Years as a teacher leader



Note: Data are weighted means combined for Core Teacher Leaders and Teacher Leaders.