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Scaling Up Three-Dimensional Science Learning Through Teacher-Led Study Groups Across a State

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Abstract

The vision for science teaching in the Framework for K-12 Science Education and the Next Generation Science Standards requires a radical departure from traditional science teaching. Science literacy is defined as three-dimensional (3D), in which students engage in science and engineering practices to develop and apply science disciplinary ideas and crosscutting concepts. This knowledge building presents many challenges for teachers. We describe a two-pronged program for scaling 3D science professional development (PD) across a state: (a) 24 teachers developed expertise in 3D learning and facilitating teacher study groups; (b) these peer facilitators led 22 study groups of teachers in 3D science activities, analyzing student learning, and investigating classroom interactions. We describe design approaches for supporting teacher and facilitator learning. We present analyses of teacher learning, including shifts in 3D science, beliefs, and pedagogical content knowledge that supports 3D science teaching, and consider implications for scalable design approaches for supporting science teacher learning.

Keywords

professional development, science education, standards, teacher leadership, professional learning communities

Introduction

The new vision for science learning and teaching established in the *Framework for K-12 Science Education* (National Research Council, 2012) and carried forward in the Next Generation Science Standards (NGSS Lead States; 2013) requires a radical departure from typical approaches to teaching and learning in science classrooms K-12 (Banilower et al., 2013). The Framework and NGSS articulate a vision of *three-dimensional (3D) learning*, identifying science literacy as the interaction of science and engineering practices, disciplinary core ideas (DCIs), and crosscutting concepts. Students engage in science and engineering practices to develop and use science ideas to make sense of phenomena or solve problems (National Research Council, 2015). Yet supporting learners in these 3D knowledge-building practices presents many challenges for teachers unaccustomed to these approaches. To achieve these reform-based changes, teachers will need more than alignment between standards, curriculum, and assessments. Many K-12 science teachers will need substantial professional development (PD) to adapt their teaching practice to support science practices, focus on explanatory ideas, and help students build ideas over time. This is needed whether a state seeks to implement NGSS or update their standards drawing on the research-based recommendations of the Framework.

We describe a program that begins the process of scaling PD for 3D science learning across a state. The core of the program involved peer-facilitated teacher study groups. To develop these peer facilitators, we designed a complementary program strand to support teacher facilitators in also developing expertise in facilitating teacher study groups.

We begin with the learning goals for the PD, and describe our design approaches for supporting teacher learning about how to bring 3D science into classrooms, and for supporting development of facilitation expertise. We consider how these principles are reflected in the design of the PD. We then

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present analyses of the learning and belief shifts among teacher participants and consider the implications of these results for scalable design approaches for supporting science teacher learning.

What Are the PD Challenges for 3D Science Learning?

There are three areas of contrast between much current practice and the approaches to teaching and learning articulated in the Framework and NGSS (Reiser, 2013).

1. Learning goals focus on disciplinary core ideas (DCIs) that are generative and powerful explanatory tools for explaining and making sense of the natural and designed world.
2. Students use science and engineering practices to develop and apply these explanatory ideas.
3. Students build these ideas incrementally, revisiting and building on the ideas over time, connected to and motivated by questions arising from phenomena.

These three shifts need to work together. To develop and use explanatory ideas, students need to focus on investigating and explaining *how* and *why* phenomena occur as they do in the natural world. Hence, building and using these explanatory ideas requires that learners do so by engaging in the central scientific practices, particularly constructing explanatory models (Berland et al., 2016; Passmore, Gouvea, & Giere, 2014; Schwarz et al., 2009), using scientific argumentation from evidence to evaluate and decide between competing models (Passmore & Svoboda, 2012), and applying scientific models to construct explanations for phenomena (Braaten & Windschitl, 2011; Windschitl, Thompson, & Braaten, 2008).

When knowledge building is viewed as a "practice" rather than as "inquiry" or "science skills," the shift is more than nomenclature. It involves re-envisioning students' science work as a meaningful, purposeful attempt to build knowledge:

> Seeing science as a set of practices shows that theory development, reasoning, and testing are components of a larger ensemble of activities that includes networks of participants and institutions [10, 11], specialized ways of talking and writing [12], the development of models to represent systems or phenomena [13-15], the making of predictive inferences, construction of appropriate instrumentation, and testing of hypotheses by experiment or observation [16]. (National Research Council, 2012, p. 43)

These changes in classrooms require a shift from *learning about* scientific ideas to *figuring out* scientific ideas that explain how and why phenomena occur (Schwarz, Passmore, & Reiser, 2017). This requires rethinking the nature of teaching and learning, the classroom interactions that build science knowledge, and the types of practices teachers need to support in their classrooms (Wilson, 2013).

A Professional Learning System to Support Science Teachers' Learning in, From, and for Practice

Addressing these fundamental classroom shifts requires helping teachers go beyond *learning about* these reforms, to work on applying these reforms to their own classroom practice. Lampert (2009) terms this "learning in, from, and for practice," in which teachers analyze examples of classroom practice and work together to plan how to apply these ideas to their own classroom. This approach to PD is often termed "practice-based professional learning" (Ball & Cohen, 1999).

A Hybrid Face-to-Face and Online System for Professional Study Groups

The PD sessions for both peer facilitators and teacher study group participants investigated in this article employed a hybrid model of PD, the *Next Generation Science Exemplar System* (NGSX; Moon, Passmore, Reiser, & Michaels, 2014; Reiser, Michaels, Moon, & Passmore, 2014). In these sessions, facilitators support face-to-face study teacher study groups as they work through multifaceted discussion-based learning tasks organized and supported by online resources. These include rich video cases for analysis, guidance from short tutorial videos and readings, and scaffolding tools to help teachers analyze teachers' and students' work in classrooms, and for facilitators-in-training to analyze cases of facilitators' and teachers' work in study groups.

In a typical session, a study group of 20 teachers meets for 3 to 5 hr. A video from an online guide (a teacher, education researcher, or scientist) introduces the theme for the unit, such as the nature of modeling, support for classroom discourse, or difficulties students face in reasoning about particular scientific ideas (e.g., the particle nature of matter). Units include examples of student work or video cases to analyze, with focused prompts for whole group or small group discussion (see Figures 1-2). Work is assigned between sessions, such as readings about the science practices or students' learning of the subject matter, or directions to try out aspects of what they have learned in the participants' own classrooms.

We have developed two pathways or courses of study that address needed practices for classroom teachers and peer facilitators. The *Introduction to Three-Dimensional Science Learning* (Intro to 3DL) pathway helps teachers investigate how to bring 3D learning into classrooms. The *Facilitating Science Teacher Study Groups* (Facilitator) pathway helps teachers and coaches learn how to support study groups of teachers engaged in the Intro to 3DL pathway. Peer facilitators work through both pathways—They engage in the Facilitator pathway interleaved with their progress through

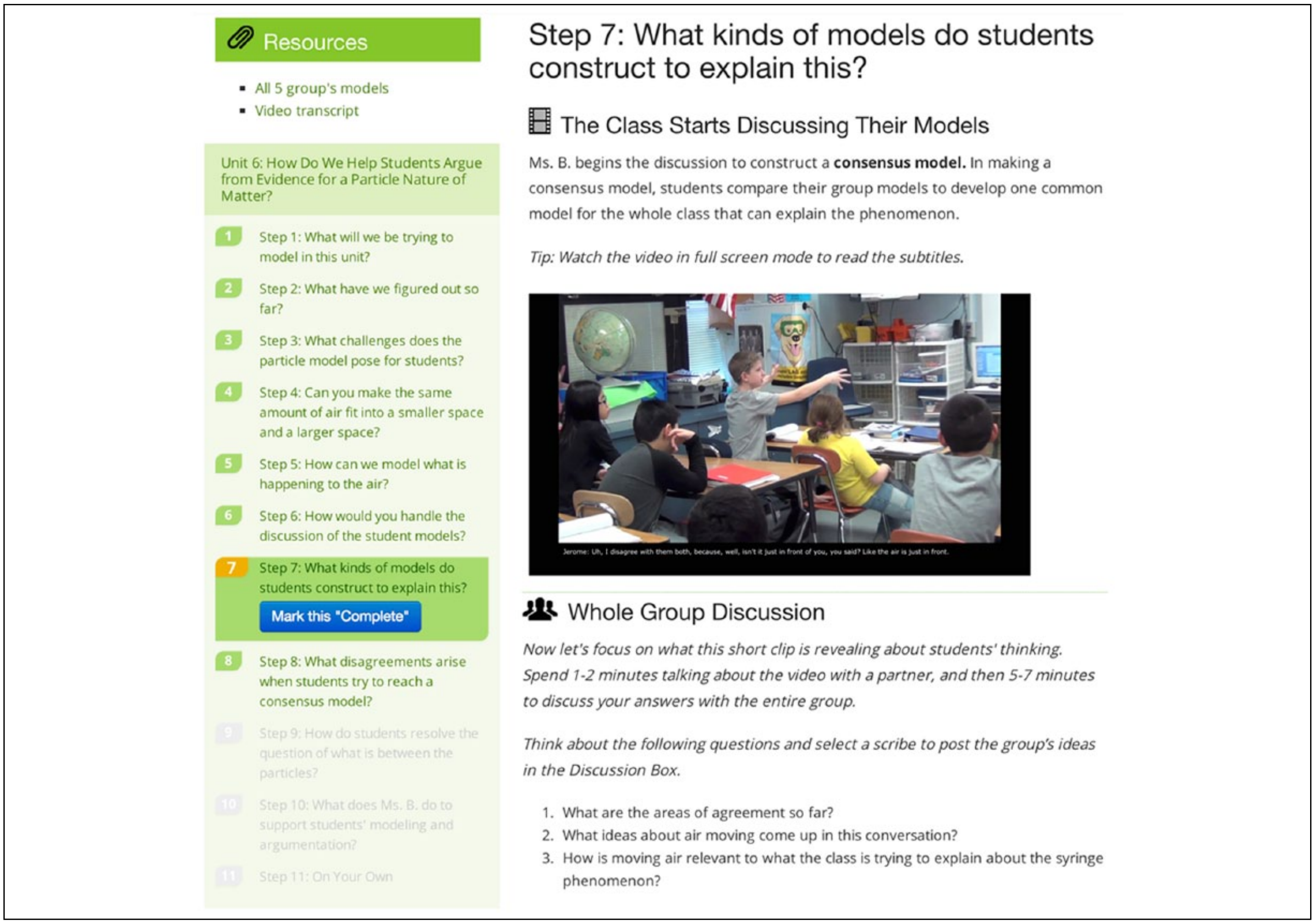


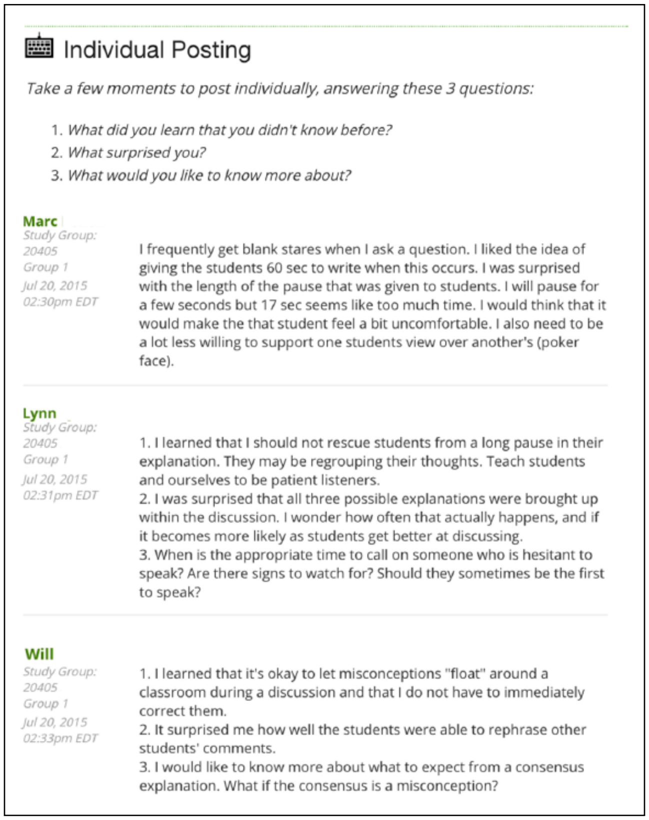
Figure 1. A step in an NGSX unit supporting teachers in analyzing classroom interactions (Unit 5).
Note. The teacher study group views the video, considers the discussion prompts, and records the results of the discussion online. The menu bar on the left shows the preceding and following steps in the unit.

the Intro to 3DL pathway. Thus, they move back and forth between two roles—investigating 3D learning and investigating how to facilitate a teacher study group working on these same issues. Our development of these pathways has been guided by design principles that draw on an emerging consensus about the features that best support teacher learning (Borko, 2004; Garet, Porter, Desimone, Birman, & Yoon, 2001; Wilson, 2013). The next sections review these design principles and their implementation in NGSX.

Design Principle 1: Situate Teacher Learning in Tasks Requiring Sensemaking of Classroom Cases

Teachers' knowledge of how to support student learning depends on understanding how general issues (e.g., building on prior conceptions) arise as students engage with *specific subject matter* issues, such as making sense of particle nature of matter (Garet et al., 2001; Putnam & Borko, 2000). One fruitful way to investigate subject matter learning issues is to analyze records of practice such as classroom video cases (Ball, Sleep, Boerst, & Bass, 2009; Boerst, Sleep, Ball, & Bass, 2011; Sherin & Han, 2004; van Es & Sherin, 2008). Video cases enable teachers to analyze student thinking, how other teachers elicit and work with student ideas, and how students' work with subject matter is realized in classroom discourse (Boerst et al., 2011; Borko, Jacobs, Eiteljorg, & Pittman, 2008). Cases also enable teachers to explore how tasks in curriculum materials can provide experience with phenomena, raise questions, and help students construct explanations (Ball & Cohen, 1996, 1999; Borko et al., 2008).

Video cases in NGSX are situated in specific classroom examples, such as students developing explanatory models of molecular motion to explain diffusion. The cases enable teachers to follow a classroom aligned with the vision of NGSS through a series of episodes exhibiting the storyline of their investigation, as students identify questions about phenomena, construct models to explain their results, and engage in argumentation to evaluate and refine their models through further investigations. These rich cases provide the context for teachers to consider how they might foster similar engagement in their own classrooms.


Individual Posting

Take a few moments to post individually, answering these 3 questions:

1. *What did you learn that you didn't know before?*
2. *What surprised you?*
3. *What would you like to know more about?*

Marc
Study Group: 20405
Group 1
Jul 20, 2015 02:30pm EDT

I frequently get blank stares when I ask a question. I liked the idea of giving the students 60 sec to write when this occurs. I was surprised with the length of the pause that was given to students. I will pause for a few seconds but 17 sec seems like too much time. I would think that it would make the that student feel a bit uncomfortable. I also need to be a lot less willing to support one students view over another's (poker face).

Lynn
Study Group: 20405
Group 1
Jul 20, 2015 02:31pm EDT

1. I learned that I should not rescue students from a long pause in their explanation. They may be regrouping their thoughts. Teach students and ourselves to be patient listeners.
2. I was surprised that all three possible explanations were brought up within the discussion. I wonder how often that actually happens, and if it becomes more likely as students get better at discussing.
3. When is the appropriate time to call on someone who is hesitant to speak? Are there signs to watch for? Should they sometimes be the first to speak?

Will
Study Group: 20405
Group 1
Jul 20, 2015 02:33pm EDT

1. I learned that it's okay to let misconceptions "float" around a classroom during a discussion and that I do not have to immediately correct them.
2. It surprised me how well the students were able to rephrase other students' comments.
3. I would like to know more about what to expect from a consensus explanation. What if the consensus is a misconception?

Figure 2. Responses in NGSX to an individual reflection, from Unit 4 on teacher talk moves and supporting the classroom discourse needed for science and engineering practices.

Design Principle 2: Focus PD on the High-Leverage Practices of Argumentation, Explanation, and Modeling

Studies of changes in teacher practice suggest the importance of focusing on "high-leverage practices" that have high payoff in catalyzing changes in classroom pedagogy (Ball et al., 2009; M. S. Smith & Stein, 2011; Windschitl, Thompson, Braaten, & Stroupe, 2012). The practices in the Framework that emerge as most challenging for teachers are explanation, developing and using scientific models, and argumentation (Banilower et al., 2013; Osborne, Erduran, & Simon, 2004; Windschitl et al., 2008). Yet these three are central to this vision of meaningful science practice (Schwarz et al., 2017). The centrality of modeling reflects the emphasis on building the central disciplinary ideas that are most generative for developing explanations of the natural world (Berland et al., 2016; Passmore et al., 2014; Windschitl et al., 2008). Furthermore, modeling and explanation necessarily require argumentation to evaluate and compare competing accounts and develop consensus ideas (Passmore & Svoboda, 2012; Schwarz et al., 2009). In NGSX, videos of expert commentary, science tasks for teachers to perform, examples of student work, and classroom cases all involve developing, testing, and refining models that can explain phenomena, and engaging in argument from evidence to guide these processes.

Design Principle 3: Help Teachers Connect What Is New About the Science, Student Thinking About the Science, and Pedagogical Supports for the Science

Changing classroom practice requires a coherent approach to changes in the learning environment, drawing on understanding of student learning, curriculum and tasks, and teaching approaches (Ball & Cohen, 1999). Thus, effective PD needs to engage teacher learners in tasks with multiple lenses: (a) engaging with disciplinary practices as learners, (b) analyzing students' engagement in these practices, and (c) analyzing pedagogical approaches to support these practices (Borko, 2004; Roth et al., 2011). In NGSX, participants develop, argue for, and refine explanatory models for phenomena exemplifying the target science (e.g., nature of matter, how sound travels, how plants grow); analyze students engaged in the same practices with the same subject matter; and analyze how teachers support these practices and the classroom discourse that enacts these practices (Michaels & O'Connor, 2015).

Design Principle 4: Organize Teacher Study Groups Working to Apply the Reforms to Their Own Classroom Practice

Teachers need the opportunity to analyze cases and apply the strategies themselves (Garet et al., 2001; Wilson, 2013). The substance of the work needs to *be connected to issues of teachers' own practice* (Ball & Cohen, 1996; Borko, 2004; Garet et al., 2001; Wilson, 2013). Teachers need sufficient opportunities and support to apply the strategies and figure out changes in their own practice (Darling-Hammond, 1995; Putnam & Borko, 2000).

NGSX supports teachers in the first part of this process—figuring out what the implications of the reform ideas are for their own practice. Working through multiple cases helps identify the classroom implications of a reform idea, such as how to support students in using argumentation to evaluate competing models. Tasks support teachers in applying what they are figuring out to their own teaching context. Teachers work together to integrate sensemaking discussions into their current units and to redesign one of their current units to incorporate argumentation, explanation, and modeling.

Design Principle 5: Develop Peer Facilitators' Expertise in Knowledge-Building Facilitation

Supporting teacher study groups as they explore how to bring the reforms into their own practice cannot rely on traditional approaches to PD instruction that emphasize content delivery by "experts." PD facilitators need to engage in *knowledge-building facilitation* in which they strategically support participants in co-constructing new understandings with colleagues. They need pedagogical content knowledge (PCK) about facilitation to understand how to support teacher learning from cases of practice (Borko, Koellner, & Jacobs, 2014; van Es, Tunney, Goldsmith, & Seago, 2014). To support this, the Facilitator pathway helps prepare teachers, coaches, and other instructional leaders to become expert facilitators of teacher study groups.

Design Trade-Offs: Balancing the Situated Nature of Teacher Learning With Application to Their Own Classrooms

These design principles suggest that professional learning should begin with teachers investigating concrete examples from practice, analyzing the key shifts in cases of the reform in action, planning changes to their own practice, and then engaging in cycles of classroom enactment, analysis, and reflection. The NGSX design aims to address the design trade-offs that emerge when situating teacher learning in their experiences as 3D science learners and making sense of specific examples of classroom cases (Principles 1-3), while also supporting them in making connections to their own practice (Principle 4). Connecting teachers' experiences doing modeling, argumentation, and explanation with the classroom examples they analyze requires having a common subject matter context across these activities. We also wanted to constitute study groups with distributed expertise that would support collaboration across grade bands and science disciplines, so we asked our district collaborators to assign teachers to study groups to balance grade band and discipline. For these reasons, we settled on a single subject matter context with a broad range of applicability (matter and its interactions) and multiple grade bands as a common context to experience and analyze classroom examples of 3D learning in the first two thirds of the pathway. Then, the last one third of the pathway supported connections back to their own practice, as teachers in grade- and subject-specific groups applied what they learned to design classroom tasks and assessments for their classrooms. Thus, the common context enables cross-grade band and discipline collaboration, and the design and application part of the pathway enables teachers to apply what they learned to make concrete changes in their own practice.

Initiating the Process of Classroom Reforms

In this article, we focus on the first part of the professional learning process, in which teachers make sense of the reforms and begin to explore the implications for their own practice. We begin with teachers' early encounters with the reform and follow them through the pathway as they engage in design work to redesign aspects of their own teaching. While following these teachers into the classroom would eventually be critical for documenting the intended effect of the professional learning on their own students' learning, this study is limited in its focus on the first essential step in that process in the initial summer of a statewide effort, as teachers make sense of the reforms and apply what they are learning to identify and plan the changes they need to make in their own classrooms.

The Introduction to 3D Science Learning Pathway

The Introduction to 3D Learning pathway consists of seven units comprising about 45 hr of sessions. As described earlier, teachers take multiple perspectives: engaging in 3D science learning themselves, analyzing student work and growth in students' ideas through artifacts and video cases, and analyzing teaching strategies in classroom video cases.

Units 1 to 3 engage participants in the practices of modeling, argumentation, and explanation as they grapple with phenomena related to the particle model of matter. They develop the DCIs through science practices as they participate as learners. In addition, they analyze the pedagogical shifts in the Framework and NGSS as they consider the implications for making modeling, argument, and explanations central in the knowledge building of students. Unit 4 focuses on tools and strategies that teachers can use to build an equitable classroom culture of academically productive talk needed to support argumentation, explanation, and modeling. In Units 5 and 6, participants study video cases of middle and high school classrooms working with these same science issues. They explore the instructional decisions and structures to support students in learning science through participation in the practices. The 3-day Unit 7 supports teachers in taking what they have learned about the reforms to redesign elements of their own teaching. This work guides teachers in developing coherent *3D storylines* that they can use to support 3D learning for their own students. The storyline tools support organizing sequences of lessons around questions that arise through interactions with real-world phenomena, motivating investigations of these phenomena through science practices, to incrementally develop and use DCIs (Reiser, Fumagalli, Novak, & Shelton, 2016).

The Facilitator Pathway for 3D Science Learning

The *Facilitator Pathway* is a 20-hr course organized into five chapters, 3 to 4 hr in length, that peer facilitators study interleaved with the Intro to 3DL pathway. It addresses *productive knowledge building*, as teachers examine issues such as helping study group participants go public with their arguments and explanations of phenomena; building capacity for participants to take one another's scientific thinking seriously; helping participants dig deeper into the pedagogical shifts that support students' modeling, argumentation, and

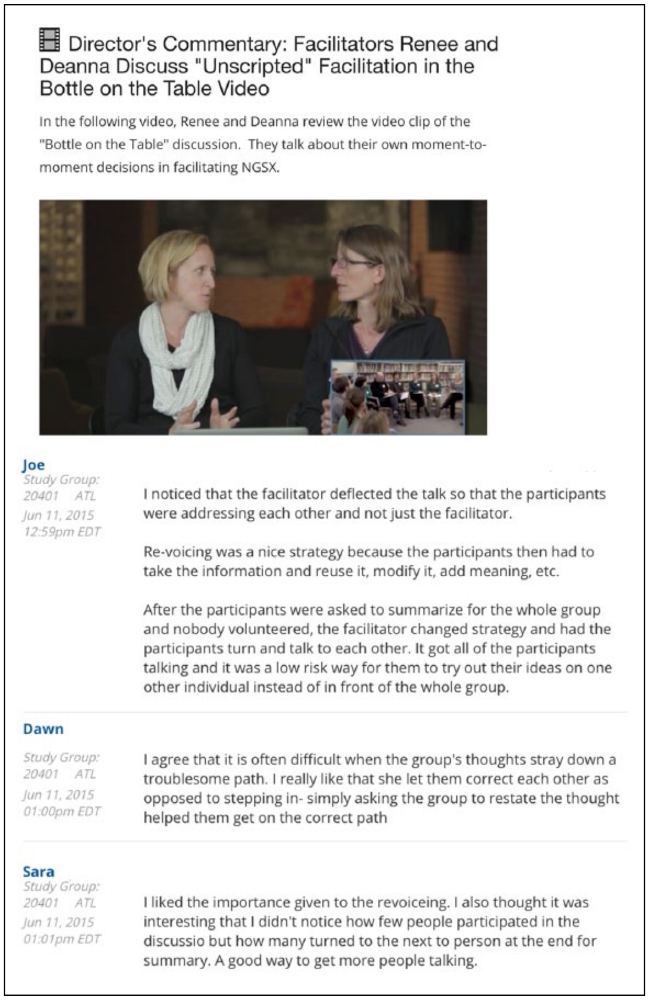


Figure 3. Participants' posts of their individual analyses of a teacher study group episode and the facilitators' reflections in the NGSX Facilitating Teacher Study Groups pathway.

explanation; and positioning oneself as a peer in the study group's sensemaking process.

Culture-building strategies are supported to establish and sustain study group norms on respect, risk-taking, equity, and collaboration, in which knowledge building can happen for everyone, regardless of grade level, science background, or prior knowledge of the Framework and NGSS. Finally, the pathway aims to support PCK for facilitators (e.g., Borko et al., 2014; van Es et al., 2014). This includes strategies for supporting teachers in helping students engage in science practices, supporting teachers in unpacking DCIs to plan classroom tasks and assessments, and strategies to help study group participants push beyond description to detailed analyses of classroom interactions. To support reflection on peer facilitation strategies, facilitators-in-training analyze videos of study group interactions, and then see clips of experienced facilitators debrief about the clip they have just watched (see Figure 3).

The State PD Program Design

This study examines the use of the practice-based professional learning model in the first summer of an effort to scale up PD across a Midwestern state that includes a major urban center, suburban, and rural areas. NGSX was part of a collaboration selected in 2015 to be the PD system used in the state's Mathematics and Science Partnerships (MSP) program, funded by the U.S. Department of Education MSP program (http://www.ed-msp.net/).

The State MSP PD program was designed as a 3-year program, with an intensive first summer for K-12 teachers to begin working with NGSS. This article investigates this first summer professional learning experience. The summer program was implemented in two phases. The first Request For Proposals (RFP; posted September 16, 2014) invited applications for a Lead Partnership (LP) to manage the PD Network. A subsequent RFP (posted February 13, 2015) invited proposals for up to 11 regional Science Area Partnerships (SAPs), distributed across the state's six geographical regions, to recruit at least twenty K-8 teachers and twenty 9-12 teachers each.

The PD program began in summer 2015. The state agency awarded a Lead Partnership and 11 SAPs, including two partnerships from the urban center. The lead partnership selected 24 teachers to become facilitators in positions the MSP called "Area Teacher Leaders" (ATLs). In Phase I, NGSX lead facilitators worked with the 24 ATLs for 10 days across 3 weeks in the Introduction to 3DL and Facilitator pathways. Phase II followed 2 weeks later, in which ATLs, guided by what they learned about knowledge-building facilitation and 3D learning, led study groups for 9 days (across 3 weeks) through the Introduction to 3DL pathway. The 24 ATLs served as peer facilitators for 22 study groups at the 11 regional partnerships across the state. Most groups were led by a single ATL; in two sites, three ATLs were split between two study groups; and in one site, two ATLs worked together. A total of 420 teachers completed the study groups across the 11 partnerships.

The aim of the 3-year MSP intervention was to effect changes in teachers' practice so they could more effectively support students' 3D learning. We investigated teacher participants' growth during this first summer, in which ATLs worked with participants to help them engage in, analyze, and plan classroom tasks for 3D science learning. We examined three research questions about the effects of PD situated in classroom practice on teacher's knowledge, attitude, and beliefs needed to plan, enact, and support classroom interactions with students:

> **Research Question 1:** How does PD focused on classroom practice help teachers improve their proficiency with 3D science?
> **Research Question 2:** How does PD focused on classroom practice influence teachers' confidence and beliefs about learning and teaching consistent with 3D learning?

Research Question 3: How does PD focused on classroom practice help teachers develop PCK needed to support 3D learning?

Method

The data for teacher growth come from online surveys given at the beginning and end of the summer PD. The pre-survey was administered online through an email link sent to all participants 1 week prior to the start of the PD. The post-survey was administered on the last day of PD. Of the 420 teachers completing the PD, 241 (57%) participants consented to be a part of the research. Teachers were not compensated for participating in the research activities. Of the 241 teachers who consented to be a part of the research, all teachers completed the pre-survey, and 198 (82%) completed the post-survey.

Both pre- and post-surveys included sections to examine teachers' ability to engage in 3D science reasoning and rating items to assess their attitudes, beliefs, and goals across a range of teaching issues. They also included constructed-response items to assess their reasoning about classroom situations involving science practices. Among the attitude and belief items, items about instructional preparedness, instructional goals, and beliefs were selected from the *2012 National Survey of Science and Mathematics Education* (Banilower et al., 2013) and from the *Teacher Beliefs About Effective Science Teaching Questionnaire* (P. S. Smith, Smith, & Banilower, 2014). The 3D science reasoning and the other attitude and belief items were developed specifically for studies with NGSX PD, and have been pilot tested with over 300 teachers participating in earlier studies.

The pre-survey also asked teachers about their background (e.g., gender, teaching certification), teaching position, and how they became involved in the PD. On the post-survey, a constructed-response item asked teachers to describe the two most important things they learned during the PD.

We developed composites to group related items into clusters from the quantitatively measured items common to the pre- and post surveys. These included the scored 3D science items and the rated attitudes, goals, and beliefs items. We developed these composites in prior studies, and tested the composites using confirmatory factor analysis with data from the current group of participants. The reliabilities of the scales were calculated using Cronbach's alpha, and ranged from .70 for 3D Science Learning to .94 for Preparedness to Incorporate Science and Engineering Practices. Composite scores were developed in *R* (R Core Team, 2015) with the *ltm* package (Rizopoulos, 2006) using Rasch modeling with a partial credit structure with pre- and post-responses scaled together. (See the appendix for the individual items for each composite.)

3D Science Learning

To investigate Research Question 1, we designed items to measure teachers' proficiency in developing explanations of phenomena involving the particle nature of matter. These included six multiple-choice items and one constructed-response item, which asked participant to explain "how a vacuum cleaner works to pick up dirt," including "what makes the dirt go into the vacuum cleaner." The items asked participants to engage in modeling, explanation, and argumentation from evidence about matter interactions in everyday phenomena, the anchoring context for the first two thirds of the work in the pathway. The composite score combined the correctness of multiple-choice items and the scored constructed-response item.

To investigate Research Question 2, shifts in teachers' confidence and beliefs consistent with 3D teaching and learning, we developed the following items and composites:

Confidence With the Framework and NGSS

Two items asked teachers to judge "how confident do you feel with respect to teaching science in the ways called for in . . . " the Framework and NGSS on a 5-point scale from *unfamiliar* to *very confident*. (The two items were not combined into a composite.)

Planned Emphasis on Science Instructional Goals

This composite included five items asking teachers to rate instructional goals according to "how much emphasis will each receive in your classroom." The items consisted of widely accepted science goals, not specific to science education reforms but consistent with them (such as *understanding science concepts* and *increasing students' interests in science*).

General Instructional Preparedness

This composite included six items asking teachers to rate how prepared they feel for particular instructional tasks. These reflected general aspects of teaching, not specific to the Framework and NGSS, such as *anticipate difficulties that students may have with particular science ideas and procedures.*

Preparedness to Incorporate Science and Engineering Practices

This composite included items asking teachers to rate the eight science and engineering practices on a 4-point scale to judge "how well prepared do you feel to support students in each of the following science and engineering practices?"

The next three composites include items that asked teachers to rate their agreement on a 6-point scale with relevant belief statements about teaching and learning.

Beliefs About Traditional Instruction

This composite included eight belief items that addressed teaching approaches typically identified with traditional teaching, which we viewed as obstacles to implementing the

Framework and NGSS, such as "Teachers should explain an idea to students before having them consider evidence that relates to the idea."

Beliefs About Students Engaging With Evidence

This composite included five belief items that referred to students using evidence to develop science knowledge, consistent with the Framework and NGSS, such as "Students should use evidence to evaluate claims about a science concept made by other students."

Beliefs About Using Student Ideas

This composite included six belief items that referred to the connections between students' and scientific ideas, such as "Teachers should provide students with opportunities to connect the science they learn in the classroom to what they experience outside of the classroom."

PCK for Science Practices

To investigate Research Question 3, we included three constructed-response clusters that asked teachers to describe exemplars of classroom activities with particular characteristics. One cluster asked teachers to describe "a good example of an activity in which students are developing and using models." A second focused on argument from evidence, and a third asked teachers to describe a good example of a whole-class science discussion. We designed these to assess teachers' understanding of how to use these science practices in classroom settings, thus assessing a key aspect of PCK needed to bring these practices into classrooms (Gess-Newsome, 2015). The cluster on developing and using models produced responses that reflected a broad range of practices (including references to argumentation from evidence, a focus on explanatory ideas, and investigations as sources of evidence for students' claims). Thus, we focus on these responses as indicative of teachers' knowledge about how to structure tasks to support science practices in the classroom.

Participants

The 24 ATLs included 18 females and six males and represented districts from across the state. They included four elementary, six middle school, and 14 high school teachers.

Each of the 11 SAPs acted as PD site and selected teachers for their study groups. The 11 SAPs selected a total of 420 participants. All participants taught science at the K-12 level, including some who taught multiple subjects, such as elementary teachers and special education teachers, with most being specialist teachers who only taught science. An additional 16 teachers registered to attend the PD, but withdrew prior to the first session. These teachers are not included in the numbers of participants. There was no attrition during the 10-day training.

The SAPs attempted to recruit a balance of teachers across grade bands. Of the 241 consented teachers' current teaching positions, 36% were elementary, 26% were middle school, 37% were high school, and 6% did not respond (some teachers' position included more than one grade band). The PD goals ranked as most important by teachers were (a) to learn how to adapt their teaching to be aligned with NGSS (35%), and (b) to get activities to do in their classroom that align with NGSS (27%). Fewer teachers ranked working with other teachers (10%) or learning "science content" (4%) as their most important reason for participating.

Ten of the 11 SAP sites split teachers into two study groups. SAP staff formed group to ensure an equal distribution of grade levels across the two groups and to be sensitive to networking opportunities and to interpersonal relationships that might affect the collaborative learning environment of the PD. In total, the second phase included 21 different NGSX study groups ranging from eight to 32 participants.

Analysis Approaches

Analyses of teacher change. We analyzed pre–post impact through matched-pair t tests on the seven composites. We conducted Wilcoxon signed-rank tests on the two items about teachers' confidence in implementing the Framework and NGSS, as well as the scored PCK items. Due to multiple tests, we used a Bonferroni correction for an effective significance level of .005 for the 10 primary effects tested. To explore changes on individual items within composites, we completed a Wilcoxon matched-pairs signed-rank tests for items with an ordinal scale, and a two-proportion z-test for binary items. We computed effect size for all statistically significant differences on the composites using Cohen's d. For individual items, we computed effect sizes using Cliff's delta for items with an ordinal scale and with Cohen's h for binary items. We conducted all pre–post impact tests in STATA.

Analysis of differences in impact by study group and teaching position. As the PD was implemented in 21 different study groups and with teachers across K-12, we explored differences in the impact across these different types and groups of teachers. We used a one-way ANCOVA for each composite score with the pre-score as the covariate to investigate whether there were differences by group in the pre–post change on the composites. We tested each composite separately, and ran different models to examine differences between study groups and teacher's grade level taught. For models examining differences by teachers' grade level, we conducted post hoc analyses for statistically significant differences using Tukey's honestly significant difference (HSD).

Results and Discussion

We examined multiple aspects of teachers' knowledge, attitudes, and beliefs to investigate how practice-focused PD helped teachers develop (a) proficiency in 3D science, (b) shifts in confidence and in beliefs about science teaching and learning supportive of the Framework and NGSS, and (c) PCK needed to begin working on implementing classroom change. We also examined teachers' self-reports of what they learned and present examples where their statements help elaborate the observed empirical shifts.

> **Research Question 1:** How does PD focused on classroom practice help teachers improve their proficiency with 3D science?

Our goal is to investigate the advances teachers made as 3D science learners. Many science teachers are unfamiliar with how to support students in modeling, explanation, and argumentation to build scientific knowledge (Windschitl et al., 2008). A necessary prerequisite in helping students engage in these practices is for teachers to be able to engage in these practices *themselves*. A challenge in assessing teacher growth in this study is the use of a common subject matter context to provide common experiences for teachers across grade bands and science strands. Although teachers worked in their own subject matter for the last third of the pathway, we did not know in advance what subject matter they would select, nor was it feasible to formulate 3D science assessments in all these domains. Thus, as a first measure of whether they show growth in using the three dimensions of the Framework to explain phenomena with disciplinary and crosscutting science ideas, we assessed teachers' ability to address explanatory questions about this common subject matter context, the behavior of matter.

To score the vacuum cleaner constructed-response item, we developed and refined a scoring rubric based on pilot data. The scale examined the degree of mechanism in participants' explanations, and captured a shift from intuitive ideas about vacuums "sucking" air to a more mechanistic account involving molecules in movement that collide and push one another (see Table 1). Responses from both the pre-survey and post-survey were de-identified, blinded with respect to pre- or post-response, and scored simultaneously by one researcher. A second coder scored 12% of the responses, with a Cohen's kappa of .73. The composite 3D science learning score combines this constructed-response score with their multiple-choice 3D science questions.

Teachers' 3D science learning scores increased dramatically from pre-survey to post-survey, from −0.41 to 0.59, $t(176) = 17.27, p < .001$, effect size = 1.03. These higher scores reflect more accurate and more mechanistic explanations for the phenomena on the post-survey. The effect size indicates a large gain in teachers' science progress in working with explanations and models of phenomena involving matter.

While the goals of the PD go beyond teachers simply "learning the science," PD activities to analyze the key shifts in the Framework and NGSS rely on teachers' own experiences grappling with the science. For example, teachers unpacked the science practices of argumentation, explanation, and modeling to articulate indicators of what one would see teachers and students doing and saying when engaged in these practices. Teachers began this unpacking by reflecting on their own experience in Units 1 and 2 in which they developed models to explain the behavior of matter. They built upon this unpacking as they added a focus on discourse (Unit 4), and analyzed middle and high school students' engagement in these practices (Units 5-6). Thus, establishing that teachers developed an increased ability to engage in modeling, explanation, and argument in the context of matter establishes this important element needed for the deeper learning about student thinking and pedagogy.

Consistent with this, a majority of teachers identified the students' role in the knowledge-building aspect of science practices as a central outcome for them. Some of these comments specifically identified the importance of their own experience as science learners for understanding these shifts. For example, one teacher identified the importance of developing, rather than being told, the model or being told what was incomplete about their intuitive ideas (such as suction):

> I saw what it was like to learn without having a teacher tell me everything, and I will remember that much longer than if I was just told the . . . model [for the particle nature of matter] right away, or what happens instead of suction.

> **Research Question 2:** How does PD focused on classroom practice influence teachers' confidence and beliefs about learning and teaching consistent with 3D learning?

We examined shifts in teachers' feelings of confidence and preparation, planned goals, and beliefs about learning and teaching relevant for 3D learning.

Change in Confidence in Teaching With the Framework and NGSS

Teachers reported an increase in confidence in teaching science in the ways called for by the Framework and NGSS. The median responses for confidence level shifted from *somewhat confident* to *confident* for teachers' judgments for both the Framework and NGSS. The proportion answering *confident* or *very confident* increased from 10% to 47% for the Framework and from 19% to 55% for NGSS. A Wilcoxon signed-rank tests revealed significant shifts with moderate effect sizes, $z = 9.69$, $p < .001$, effect size = 0.63 for the Framework, and $z = 9.50$, $p < .001$, effect size = 0.60 for NGSS.

Table 2 summarizes the quantitative composite measures for Research Question 2 presented in the next three sections.

Change in Teachers' Planned Emphasis on Science Instructional Goals

When asked about instructional goals generally consistent with reform science, teachers rated their planned level of emphasis in their classrooms more highly after the PD,

Table 1. Scoring Criteria for Teacher Performance on 3D Science.

Score	Scoring rules	Sample responses
Low (0)	Uses the idea of pulling the air, e.g., referring to "suction," "sucking," "pulling" or other term that reflects a similar force	• There is a suction system that pulls the dirt into the canister. • A motor inside the vacuum creates suction by changing the air pressure. Brushes on the bottom of the vacuum spin and hit the carpet to loosen the dirt. The suction can then pull the dirt from the carpet.
Developing (1)	Does not draw on a pull on the air or "suction." Instead refers to a stronger force on both sides such as pressure.	• Atmospheric pressure causes dirt to go into the vacuum. There is less pressure inside the vacuum and more outside. • Air is moving from area of high pressure to area of lower pressure.
High (2)	Unpacks the idea of unequal pressure to include why the "pushing" is stronger outside.	• The space inside the vacuum bag increases, giving the air molecules more space to move around. Also the force the outside air molecules are exerting is greater, thus pushing more air molecules and dirt into the vacuum. • When the vacuum is turned off, the air pressure outside the vacuum and inside the vacuum is equal. When the vacuum is turned on, the pressure on the outside become higher than the pressure on the inside because air is exiting the inside. This causes the air molecules on the outside to push harder and to push dirt and dust particles into the vacuum thus producing the "sucking" action.

shifting from −0.24 to .17, $t(167) = 5.93$, $p < .001$, effect size = 0.38. Although the goals involved, such as *understanding science concepts* or *learning about real-life applications of science*, do not differentiate the Framework and NGSS from earlier science standards-based reforms, these issues did arise as part of the teachers' work on the Framework and NGSS. Thus, it is perhaps not surprising that teachers reported planning to give these goals more emphasis following the PD.

Change in Teachers' General Instructional Preparedness and Preparedness to Incorporate Science and Engineering Practices

These items asked how prepared teachers felt for a variety of instructional demands. The General Instructional Preparedness composite included teaching demands generally associated with good science pedagogy, such as *monitor student understanding* and *assess student understanding*, but not particularly ones that differentiate the Framework and NGSS from other approaches. Here teachers exhibited a modest shift in how prepared they felt to do these in instruction, −.20 to .25, $t(168) = 4.29$, $p < .001$, effect size = 0.29. In contrast, when asked how prepared they felt to incorporate each of the eight science and engineering practices in their instruction, teachers increased somewhat more dramatically (effect size = 0.59), shifting from −.43 to .59, $t(168)= 9.52$, $p < .001$.

These results, along with increases in teachers' reported confidence, indicate that teachers feel more prepared to implement the new standards in their classrooms. For example, one teacher wrote that the most important thing he or she learned was "How modeling, explanation, and argumentation fit into my classroom—I had some understanding of the process prior to this training but I feel much more confident about using those science practices in my classroom now." A connection between argumentation and developing science understanding was reflected in many of the responses. In fact, more than one third of teachers' responses to the most important thing they learned in the PD mentioned argumentation, discussion, or talk moves. Many of these comments explicitly connected these strategies to helping students develop explanations of scientific phenomena. The PD seemed to help teachers see how engaging students in discussion and argumentation can support students developing scientific understanding in ways aligned with the new standards.

Change in Beliefs About Teaching and Learning: Traditional Instruction, Engaging With Evidence, and Using Student Ideas

While the self-reported measures changes in confidence, preparedness, and goals are encouraging, for PD to be successful in eventually influencing the teachers' classroom practice, it must affect what teachers understand and believe about the classroom. In this section, we examine shifts in those beliefs that could either support or inhibit strategies for implementing the Framework and NGSS.

Of particular interest is the composite concerning beliefs about traditional instruction. The 2012 National Survey of Science Teachers uncovered a number of widespread beliefs that are somewhat in opposition to the pedagogical approaches required to teach with science practices (Banilower et al., 2013). Table 3 lists the items included in the Traditional Beliefs composite, and our argument for why these beliefs could pose challenges for teachers implementing the Framework and NGSS.

We saw a dramatic shift toward less agreement with these statements as a result of the PD. Teachers shifted from .33 to −.38, $t(168) = −11.50$, $p < .001$, effect size = 0.68. The PD appears to have influenced some of these traditional views that could be at odds with implementing NGSS. Responses

Table 2. Impact of the PD on Teachers' Goals, Preparedness, and Beliefs.

	n	Mean Pre	Mean Post	*SE*	Effect size	*t*-value	*df*	*p* value
General instructional preparedness	169	−0.20	0.25	0.10	0.29	4.29	168	<.001
Preparedness to incorporate science and engineering practices	169	−0.43	0.59	0.11	0.59	9.52	168	<.001
Emphasis on science instructional goals	168	−0.24	0.17	0.07	0.38	5.93	167	<.001
Beliefs about traditional instruction	169	0.33	−0.38	0.06	−0.68	−11.50	168	<.001
Beliefs about students engaging with evidence	169	−0.05	0.17	0.05	0.25	4.23	168	<.001
Beliefs about using student ideas in instruction	168	−0.05	−0.01	0.06	NA	0.70	167	.486

Note. PD = professional development.

about what teachers learned in PD were consistent with this and referred explicitly to changes in their own thinking. Here are several examples:

> . . . That we now need to teach a different way. We no longer concentrate just on vocabulary and "surface" learning. We go much more in depth and students need to be able to prove their findings.

> I could list so many things so naming only 2 is challenging. I think starting with a phenomenon along with knowing how to unpack the Framework are the 2 most important things for me. Having the students do the heavy lifting and to think like scientists wondering about things is my take away for them.

> I have also changed my thinking of how science needs to be taught.

> I have learned a whole new way of teaching science. The whole new questioning—students' discovery—the teacher no longer gives the information to the students—the students need to discover or learn the science.

The second beliefs composite included statements about students considering evidence as part of their science learning. These included statements such as "Students should consider evidence for the concept they are studying, even if they do not do a hands-on or laboratory activity related to the concept" (see the appendix). We saw teachers shifting somewhat toward stronger agreement with these statements, from −.05 to .17, $t(168) = 4.23$, $p < .001$, a small effect size of .25.

The third beliefs composite included statements about building on student ideas. While broadly consistent with the Framework and NGSS, these statements generally reflected views of good pedagogy, and were not unique to these latest reforms. These included statements such as "Students need to discuss their thinking with each other in order to learn science concepts." In contrast to the other two clusters, these beliefs did not shift significantly from pre to post, $t(167) = 0.70$, *ns*.

Research Question 3: How does PD Focused on Classroom Practice Help Teachers Develop PCK to Support 3D Learning?

Key to professional learning is connecting what teachers learn to their own classroom practices. While this study concerned the summer learning experience prior to going back into the classroom, the last one third of the PD supported teachers in planning how to adapt their current instructional practices and tasks to implement NGSS. The PCK items for science practices items asked teachers to describe classroom scenarios that reflected use of particular science practices. The item referring to developing and using models elicited responses that revealed teachers' thinking about three high leverage practices focused on in the PD (argumentation and explanation as well as modeling), so we focus our PCK analysis on this item cluster. Supporting the practice of developing and using models presents real challenges for teachers, who have limited experience helping students build conceptual models, engaging in argumentation to refine them, and using models to explain phenomena (Henze, Van Driel, & Verloop, 2007; Justi & Gilbert, 2002).

We investigated teachers' responses to this three-part question on modeling:

1. Describe what you would consider to be a good example of an activity in which students are *developing and using models*. What are students being asked to do? (Note. Please do not use any of the examples you have done in this PD, or have watched video about in this PD. Pick something different—You can use something from your own classroom, an example you have seen in somebody else's classroom, or you can make up an example.)
2. In this example activity, what is the model that students are developing?
3. What do you see as the purpose of having students develop and use models in this example?

We coded responses to the three questions together along two dimensions: (a) the purpose of the modeling activity, and (b) the type of model involved. We developed the scoring scheme for teachers' stated purpose of the modeling drawing on the literature on teachers' conceptions of modeling (Henze et al., 2007; Justi & Gilbert, 2002; Van Driel & Verloop, 1999), combined with inductively defined categories (see

Table 3. Conflicts of Traditional Beliefs About Instruction With the Reforms in the Framework and NGSS.

Traditional teaching approach from the 2012 survey of science teachers (Banilower et al., 2013)	Counterargument from the perspective of three-dimensional learning in the Framework and NGSS
Teachers should have students do interesting hands-on activities, even if the activities do not relate closely to the concept being studied.	The point of hands-on activities should be to develop DCIs. Hands-on science doesn't necessarily help students build DCIs unless they are challenged and supported in using what they observe about phenomena to construct explanations about how and why the phenomenon occurs.
Teachers should provide students with the outcome of an activity in advance so students know they are on the right track as they do the activity. When students do a hands-on activity and the data don't come out right, teachers should tell students what they should have found. Students should know what the results of an experiment are supposed to be before they carry it out.	The point of science activities is to develop evidence about phenomena so that students can build the ideas by making sense of that evidence. Known-outcome experiments usurp the opportunity for students to make sense of the evidence gathered.
Teachers should explain an idea to students before having them consider evidence that relates to the idea. Hands-on/laboratory activities should be used primarily to reinforce a science idea that the students have already learned. Students should do hands-on or laboratory activities, even if they do not have opportunities to reflect on what they learned by doing the activities.	Science practices are about knowledge building. Experiments lose value if they are solely demonstrations of known ideas. The point of investigations is to gather evidence and then involve students in the sensemaking work of explaining the findings by building explanations or models. This sensemaking work requires time and guidance for reflection.
At the beginning of instruction on a science idea, students should be provided with definitions for new scientific vocabulary that will be used.	The goal in 3D science is building explanations and models that use the DCIs. Vocabulary is useful for aiding the precision in articulating ideas, but vocabulary items themselves are not the goals. Vocabulary should be grounded on understanding the ideas, and introduced when useful for clarifying discussion. Pre-teaching vocabulary before helping students develop the ideas does not support students' development of those ideas, and can redirect the work away from sensemaking.

Note. NGSS = Next Generation Science Standards; DCI = disciplinary core idea.

Table 4). We developed a coding scheme for the type of model based on prior modeling literature (Berland et al., 2016; Passmore et al., 2014; Passmore & Svoboda, 2012; Schwarz et al., 2009) combined with inductively defined emerging categories (see Table 5). We de-identified and blinded responses with respect to pre- or post-response prior to coding. A second trained coder scored 24% of the responses, with a Cohen's kappa of .80 for model type and .69 for model purpose.

We found important changes in teachers' understanding of the use of modeling in the classroom (see Figure 4). Following PD, we found teachers generating fewer scenarios where either the task was not connected to DCI learning goals (Levels 0-2) or the model provided an opportunity only for teachers to show an idea to students (Level 3). We found teachers generating more scenarios on the post-surveys where models are part of students developing and arguing for new solutions or predictions (Level 4) and where students are developing new general explanatory knowledge (Level 5). A Wilcoxon signed-rank test indicated that teachers' purpose for using modeling in their example activity was higher on the post-test (Median = 4) than the pre-test (Median = 3), $Z = 3.78$, $p = .0002$, Cliff's delta effect size = 0.29 (a small positive effect).

These results reveal a shift from modeling as demonstrations and ways for students to observe ideas they have been already taught to a view of modeling as a *generative* practice in which students construct new ideas. This shift is critical to more sophisticated views of the developing and using models and explanations practices (Berland et al., 2016; Schwarz et al., 2009), and is a key part of using science practices as tools to build, argue for, and refine new explanatory knowledge.

Next we examined the types of models teachers described in their scenarios. In many descriptions, there was not enough concrete detail about the students' work to classify the type of model. For example, the response "Students are developing a model of the inside of the human eye with all of the structures needed in order to see" could be describing an activity in which students construct a physical model of parts or develop a conceptual model of biological functions. Approximately 22% and 26% of responses fell into this category on the pre-survey and post-survey, respectively. We also found five categories with fewer than 5% of responses (mathematical, experiment, computer program, theory, embodied), so we combined these with the Unspecified responses (see Figure 5).

We see an interesting shift in the modeling activities teachers described. When it is possible to discern the type of model, we see a decreased focus on models as physical constructions,

Table 4. Coding Scheme for Model Purpose in Practices Scenarios.

Levels	Example response
Level 0: Unspecified or non-science goals	The purpose of students developing models is to solidify knowledge and utilize (kinesthetically) higher order thinking skills to engage, promote, and encourage connections.
Level 1: Practice a skill or become familiar with a representation	In Earth science creating landscapes and then developing topographic maps of the landscapes. To get a better understanding of how a three-dimensional structure can be mapped on a two-dimensional plane.
Level 2: Doing an activity for activity's sake or completing a challenge, but no stated science idea goals.	We create a Rube Goldberg model where the students have to use at least five steps to result in breaking an egg, or some other things . . . they understand how things work better
Level 3: Demonstrate or introduce a concept to students (teach before modeling).	The students were asked to construct a model that shows [what they knew about] how the Earth revolves around the Sun and the Moon revolves around the Earth. The students get to experience the relationship and positioning of these objects in space.
Level 4: Design or predict what will happen in a new specific context.	I think a good example would be sound. You could start by showing a video of the Tacoma Narrows bridge collapse or someone breaking a glass with music. The students would use the video above and then design a model to explain why they think the bridge has collapsed or the glass has broken. I think there are many purposes. One purpose is to see where the students are in their thinking, Another purpose it to get them thinking and to explain that thinking using evidence.
Level 5: Develop and revise new generalized knowledge.	Have students watch what happens to a window when a loud music is played near it. Have students create a poster of what happened before, during, and after the music. Come up with driving questions to lead the discussion on why the windows vibrate when the music passes. The purpose is having students understand that waves travel through a medium and affect matter in different ways. It also has the purpose of [understanding that] waves could build on each other creating amplitude.

Table 5. Coding Scheme for Types of Models in Example Modeling Activity Responses.

Code	Sample responses
Physical construction	Modeling the fossil process with clay and cement.
Abstract representation (including diagrams, verbal/written explanations)	The model will be a picture showing all the forces of the car, acceleration, gravity, and friction. They model should explain how Newton's First Law is still in effect although the car eventually stops.
Mathematical model	One example might be to graph data taken in an experiment to develop a mathematical model of a system.
Experiment	Solvent lab—Experiments using sugar in specified amounts of water of varying temperatures in groups.
Computer program or digital simulation	Student could use the video game Pac-Man to help describe segmentation.
Theory	Atomic theory. Model of an atom.
Interactive or embodied demonstration/activity	In Chemistry I, students conduct an activity called "Wanna Bond!?" During this activity, students wear a necklace with an elemental ion. For example, a necklace might have Na+1 on it. Students are required to form bonds with oppositely charged ions (anions and cations). They must form at least 25 bonds, and have to switch necklaces with another classmate every five bonds.
Unspecified: Teachers' response is too vague to determine the model being used or they are speaking in general.	Students are developing a model of the inside of the human eye with all of the structures needed in order to see.

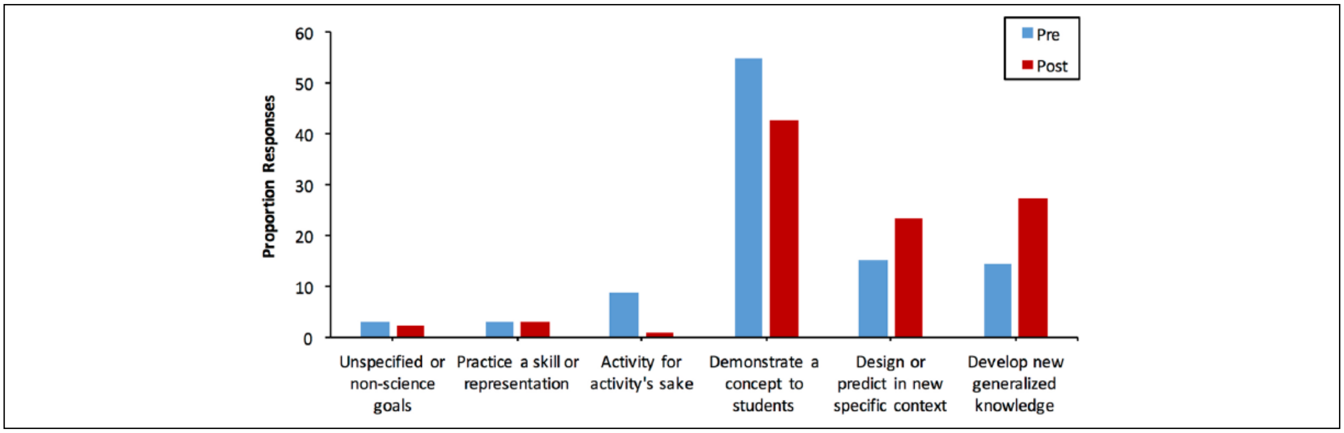


Figure 4. Shifts from pre-survey to post-survey in the purpose teachers attributed to scenarios they described as good examples of the practice of developing and using models.

and an increased focus on models as abstract and explanatory representations, such as diagrams showing molecular movement or forces. These types of abstract models are currently less frequent in classrooms, but reflect an important realization about models being used to help students explain phenomena rather than simply a physical medium through which students can represent the structure of an object (Passmore et al., 2014; Passmore & Svoboda, 2012).

This new understanding of the purpose of modeling was also reflected in teachers' responses about what they learned from the PD. For example, one teacher describes her most important area of learning as "The best way to learn science is to look at phenomena and set up models to explain what's happening. Students will have the tools to evaluate and analyze problems in a collaborative way." These results suggest that teachers developed more sophisticated understandings of modeling and explanation during the PD and were better able to construct hypothetical classroom tasks in ways that align with the new standards.

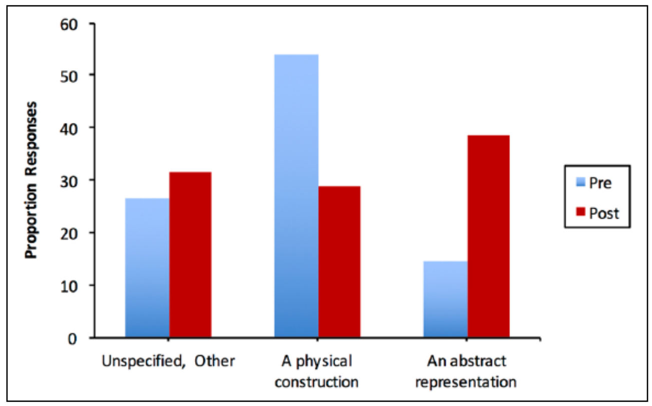


Figure 5. Shifts from pre-survey to post-survey in the types of models teachers described in their generated scenarios to exemplify students developing and using models.

Impact of the PD on Elementary, Middle, and High School Teachers

The support for facilitators explicitly addressed how to create a knowledge-building community among teachers with different kinds of expertise, and to avoid, for example, situations in which high school teachers take on the role of "explaining the science" to elementary teachers. We were eager to examine whether this approach was effective, and whether all grade bands would benefit from the professional learning.

The ANCOVA using pre-survey score as the covariate indicates that the PD produced comparable changes for all three grade bands of teachers for 3D learning, planned emphasis on goals, general preparedness, science practices preparedness, and beliefs about traditional instruction (all $p > .10$). These shifts reported above were comparable for all three populations of teachers. We find evidence of grade band differences for only two measures—teachers' beliefs about students engaging with evidence in the classroom, $F(2, 169) = 5.16$, $p = .007$; and teachers' beliefs about using student ideas in instruction, $F(2, 169) = 4.17$, $p = 0.17$. Table 6 shows the mean differences by grade band for these measures. While both middle and high school teachers shifted in their beliefs about having students engage with evidence, the elementary teachers did not. Interestingly, we see a positive change in high school teachers' beliefs about using student ideas in instruction, while the other two grade levels do not reliably shift, suggesting that actively building on students' prior conceptions may be more of a shift from existing pedagogical views for high school teachers. Overall, despite these two differences, the results support the impact of the PD on teachers' knowledge, attitude, and beliefs across all three grade bands.

Summary and Conclusions

This is an exciting time for science educators. We have advanced in our understanding of what works in science classrooms, and what could work more effectively if it were more

Table 6. Pre–Post Differences in Changes in Beliefs by Grade Level.

	Pre	Post	Difference
Beliefs about students engaging with evidence			
Elementary teachers	−0.10	−0.02	0.08
Middle school teachers	−0.12	0.10	0.22*
High school teachers	0.04	0.37	0.33*
Beliefs about using student ideas in instruction			
Elementary teachers	−0.02	−0.15	−0.13
Middle school teachers	0.03	−0.05	−0.08
High school teachers	−0.13	0.12	0.25*

*$p < .05$.

widespread. We have learned much from the successes and challenges of the last several decades of standards-based reform, leading to the Framework and NGSS. These changes are far reaching, and teachers need to be a key part of bring these reforms to life in classrooms (National Research Council, 2015). Supporting teachers' professional learning is essential, and changes in teacher practice need to involve changes in relevant teacher knowledge and beliefs (Gess-Newsome, 2015). Teachers' views of the goals of science learning and their beliefs about how students learn are as key as helping teachers learn particular strategies to implement the reforms.

We described a system of PD designed to help teachers begin to take the core shifts of the Framework and NGSS back into their own classrooms. The theory of action assumes that teachers need to understand the core shifts in the reform by investigating examples of practice, and then work on how to apply them to their own practice. This requires engaging with multiple perspectives—experiencing 3D science learning, examining student thinking and practices engaged in the same kind of knowledge building, and examining how teachers support students in those practices. This study investigated the beginning stages of this process—teachers understanding the reforms and then planning how to adapt their own classroom activity structures, lessons, and approaches to discussion.

We investigated these approaches in a two-pronged state MSP initiative that involved developing knowledge-building capacity in teachers who served as peer facilitators of study group across the state. We began by investigating how teachers experiencing 3D learning themselves produced changes in their ability to apply science practices to the DCIs they studied. We found that teachers became more proficient in using the disciplinary ideas from that domain to explain phenomena. We found that teachers' confidence and feelings of readiness to take on the challenges of the reform increased through the PD. We view these findings as suggestive—While feeling prepared or confident does not ensure the teacher are indeed capable of taking these next steps, their attitudes toward the feasibility of achieving these reforms can influence their participation in future professional learning experiences and their reaction to the inevitable challenges that will arise.

The next step examined teachers' perspectives on particular issues involved in how to engage learners in their classrooms. We analyzed relevant ideas about how to structure learning situations in their classrooms and how to interact with students. We found that teachers shifted in their views of some widely held and intuitively plausible approaches (e.g., pre-teaching vocabulary, teaching the science content prior to engaging students with evidence or phenomena). Their agreement ratings with these beliefs decreased and many specifically referenced this kind of change in their thinking in their post-survey reflections.

The most encouraging result was the increase in sophistication of teachers' reasoning about pedagogical scenarios involving science practices. Supporting learners in the discourse-rich science and engineering practices cannot occur by following routines. Teachers need a rich model of the goals, interactions, and epistemological understandings that translate knowledge building in science into grade-appropriate classroom interactions. We found teachers' reasoning about science knowledge building with increasing sophistication following the PD. Teachers showed better understanding and facility in generating situations in which models are being developed as generative tools for students to construct, argue for, evaluate, and revise explanations. They shifted from a view of models largely as physical models or models of structure to a focus on *explaining* process and mechanism. Furthermore, the vast majority of scenarios teachers generated were outside the context of models of matter, demonstrating teachers' ability to take the ideas they contextualized their work in the first part of the pathway and extend them to their own particular classroom settings.

This study presents initial evidence illustrating the promise of practice-focused PD in peer-facilitated study groups. It will be important to examine the study group interactions themselves, and explore the learning interactions that are most profitable in helping teachers grapple with the complex questions of practice. It will also be important to consider what facilitation strategies are most effective in leading study groups and how to support these strategies. Finally, a limitation in the current study is that documenting increased expertise in the teachers themselves is only the first and perhaps easiest step. Future research needs to explore whether and how this increased expertise leads to changes in classroom interactions and ultimately in student learning.

Appendix

Items Used in Composite Scores

Science Content Composite Items.

Explain as best as you can in the space below, in non-technical, everyday language how a vacuum cleaner works to pick up dirt. What makes the dirt go into the vacuum cleaner? [Constructed response]

Cindy opens a plastic sandwich bag, allowing air to get in, and then reseals it with the air trapped inside. Imagine that you could use magic super-vision glasses that allowed you to see the air particles in the sandwich bag. What would the air look like? [Select one response]

Felicia is practicing volleyball. The ball is not bouncing right so she pumps some more air into it. What happens to the weight of the ball with this change? [Select one response]

Joe retracted the plunger of a syringe as far as possible. Then he sealed the output end of the syringe—so that nothing can get in or out. He's curious about what will happen when he tries to push the plunger into the syringe. Which of the following statements do you agree with? [Select one response]

Which of the following statements best explains your reasoning? (Pick all that apply.) When Joe tries to push the plunger into the syringe . . . [Select all response]

Fred wants to practice dunking the basketball—so he wants the ball to be lighter. He decides to add some helium to his ball. When he pumps the extra helium into his ball—what will happen? [Select one response]

Which statement below best explains your answer? [Select one response]

Science Instructional Goals Composite Items.

By the end of the course/year, how much emphasis will each of the following goals receive?

Response scale (four options): None, minimal emphasis, moderate emphasis, heavy emphasis

- Understanding science concepts
- Learning science process skills (e.g., observing, measuring)
- Learning about real-life applications of science
- Increasing students' interest in science
- Preparing for further study in science

Using Scientific Practices Preparedness Composite Items

How well prepared do you feel to support students in each of the following science and engineering practices?

Response scale (four options): Not adequately prepared, somewhat prepared, fairly well prepared, very well prepared

- Asking questions and defining problems
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics and computational thinking
- Constructing explanations and designing solutions
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information

Instructional Preparedness Composite Items.

How well prepared do you feel to do each of the following as part of your instruction?

Response scale (four options): Not adequately prepared, somewhat prepared, fairly well prepared, very well prepared

- Anticipate difficulties that students may have with particular science ideas and procedures
- Find out what students thought or already knew about the key science ideas
- Implement prescribed lesson plans
- Monitor student understanding
- Assess student understanding
- Support classroom discussions drawing on student ideas

Beliefs About Traditional Instruction.

For each of the statements, state the degree to which you agree or disagree.

Response scale (six options): Strongly disagree, moderately disagree, slightly disagree, slightly agree, moderately disagree, strongly agree

Teachers should have students do interesting hands-on activities, even if the activities do not relate closely to the concept being studied.

Teachers should provide students with the outcome of an activity in advance so students know they are on the right track as they do the activity.

When students do a hands-on activity and the data don't come out right, teachers should tell students what they should have found.

Teachers should explain an idea to students before having them consider evidence that relates to the idea.

Hands-on/laboratory activities should be used primarily to reinforce a science idea that the students have already learned.

Students should do hands-on or laboratory activities, even if they do not have opportunities to reflect on what they learned by doing the activities.

Students should know what the results of an experiment are supposed to be before they carry it out.

At the beginning of instruction on a science idea, students should be provided with definitions for new scientific vocabulary that will be used.

Beliefs About Students Engaging With Evidence.

For each of the statements, state the degree to which you agree or disagree.

Response scale (six options): Strongly disagree, moderately disagree, slightly disagree, slightly agree, moderately disagree, strongly agree

Teachers should ask students to support their conclusions about a science concept with evidence.

Students should rely on evidence from classroom activities, labs, or observations to form conclusions about the science concept they are studying.

Students should use evidence to evaluate claims about a science concept made by other students.

Students should consider evidence that relates to the science concept they are studying.

Students should consider evidence for the concept they are studying, even if they do not do a hands-on or laboratory activity related to the concept.

Beliefs About Using Student Ideas in Instruction.

For each of the statements, state the degree to which you agree or disagree.

Response scale (six options): Strongly disagree, moderately disagree, slightly disagree, slightly agree, moderately disagree, strongly agree

It is better for science instruction to focus on ideas in depth, even if that means covering fewer topics.

Teachers should provide students with opportunities to connect the science they learn in the classroom to what they experience outside of the classroom.

Teachers should provide students with opportunities to apply the concepts they have learned in new or different contexts.

Students' ideas about a science concept should be deliberately brought to the surface prior to a lesson or unit so that students are aware of their own thinking.

Students should have opportunities to connect the concept they are studying to other concepts.

Students need to discuss their thinking with each other in order to learn science concepts.

Authors' Note

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