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

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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 a combination of science and engineering practices, disciplinary core ideas, and crosscutting concepts. The three dimensions are integrated, not separate learning goals. In 3D learning, students engage in the science and engineering practices to develop and use the science ideas to make sense of phenomena or solve problems (National Research Council, 2015). Yet supporting learners in knowledge-building practices presents many challenges for teachers unaccustomed to these approaches. To achieve the changes in teaching and learning in these reforms, teachers will need more than alignment between standards, curriculum, and assessments. Many science teachers across the country, K through 12, 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. Whether in states seeking to implement NGSS, or in states updating their standards to draw on the research-based recommendations of the Framework, many teachers require support for learning new tools and strategies to support a classroom culture of scientific and engineering practices.

In this paper, we describe a program for scaling up PD for three-dimensional science learning across a state. One strand of the program was designed to support the development of teacher leaders, with dual expertise in three-dimensional science learning in K-12 classrooms and in facilitating teacher study groups. In the second strand of the program, these teacher leaders facilitated teacher study groups focusing on 3D learning.

The PD sessions for both teacher leaders and study group participants employed a hybrid model of professional development. In these sessions, facilitators supported face-to-face study teacher study groups as they worked through multi-faceted discussion-based learning tasks organized and supported by an online system. The system provided an agenda of tasks, embedded expertise, video cases for analysis, and tools to support analyses of teachers' and students' classroom work.

We begin with the learning goals for the PD, and describe the design approaches for supporting teacher learning about how to bring 3D science into classrooms, and for supporting development of facilitation expertise. We describe a PD system reflecting these approaches. We then present analyses of the learning among teacher participants and consider the implications of these results for scalable design approaches for supporting science teacher learning.

What are the professional development challenges for three-dimensional 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 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 these ideas over time, connected to and motivated by phenomena.

These three shifts need to work together. In order to develop and use explanatory ideas, it is key that students explore the use of these ideas to account for *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., 2015; 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).

The shift in viewing the knowledge building as a "practice" rather than calling it "inquiry" or "science skills" is more than nomenclature – it reflects the attempt to re-envision students' science work so that it is 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 by engaging in argumentation, explanation, and modeling. For teachers, this requires important shifts in how they envision the nature of teaching and learning, the kinds of classroom interactions that build science knowledge, and the types of practices students need to be engaged in. These reflect core challenges for professional learning for teachers (Wilson, 2013).

A professional learning system to support science teachers' learning in, from, and for practice

Addressing these fundamental classroom shifts in professional development requires helping teachers go beyond *learning about* these reforms, and work on applying these reforms to their own classroom practice. It requires an approach Lampert (2009) terms "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. In this section, we draw on prior work on teachers' professional learning to motivate the design strategies explored in our PD system intended to help teachers connect the reforms to their own practice.

To address these shifts, we have developed the Next Generation Science Exemplar System (NGSX), consisting of two pathways or courses of study that address needed practices for classroom teachers and facilitators (Reiser, Michaels, Moon, & Passmore, 2014). The *Introduction to 3D Science Learning* pathway helps teachers learn how to bring three-dimensional learning into classrooms. The *Facilitating Science Teacher Study Groups* pathway helps teachers and coaches learn how to support study groups of teachers investigating three-dimensional learning. Each of these pathways combines work in face-to-face study group sessions, with the use of an on-line system that poses tasks and provides resources for each session, and for reflective work between sessions. The PD system provides rich cases for analysis, guidance through short tutorial videos and readings, and scaffolding tools to help teachers analyze teachers' and students' science work in classrooms, and facilitators analyze facilitators' and teachers' work in study groups.

The design principles that guided the specific strategies for supporting teacher learning in these two pathways are summarized in Table 1. These principles draw on an emerging consensus about the features that best support teacher learning (Borko, 2004; Garet, Porter, Desimone, Birman, & Yoon, 2001; Wilson, 2013). These tenets of effective PD provided the starting point for developing the specific design principles we have explored in our PD system (Moon, Michaels, & Reiser, 2012; Moon, Passmore, Reiser, & Michaels, 2014; Reiser et al., 2014).

Table 1. Summary of design principles in the NGSX PD system

Design Principle	How The Principle is Realized in The PD System
1. Situate teacher learning in tasks requiring sensemaking of classroom cases	Analytical tasks applied to video cases that follow classroom episodes of students engaged in science practices
2. Focus on the high leverage practices of argumentation, explanation, and modeling	Teachers analyze cases involving argumentation around explanatory models
3. Organize teacher study groups working to apply reforms to their own practice	PD tasks support teachers in incorporating science practices in their own classrooms
4. Combine focus on science, student thinking, and pedagogy	PD tasks interweave multiple perspectives, engaging teachers in science, analyzing student thinking, and analyzing pedagogical strategies
5. Develop teacher leaders' capacity in knowledge-building facilitation	Support pedagogical content knowledge for facilitation of study groups *(The Facilitator Pathway)*

Design principle 1: Situate teacher learning in tasks requiring sensemaking of classroom cases

Teachers' knowledge of how to support student learning draws on general ideas (e.g., building on prior conceptions) but critically depends on understanding how those general ideas play out when connected to *specific subject matter* issues (e.g., the particle model of matter) and the challenges students face in making sense of this subject matter (Garet et al., 2001; Putnam & Borko, 2000). One fruitful way to engage teachers with records of practice is for teachers to analyze video cases of teaching interactions (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 and the work of other teachers to elicit and work with student ideas, and provide a context to analyze how target subject matter and student thinking are realized in classroom discourse (Boerst et al., 2011; Borko, Jacobs, Eiteljorg, & Pittman, 2008). Moreover, the rich cases provide examples teachers can study to explore how tasks in curriculum materials can provide experience with phenomena, raise questions, and help students construct explanations to make sense of the target ideas (Ball & Cohen, 1996, 1999; Borko et al., 2008).

The video cases embedded in our PD system exemplify general issues for a scientific practice, such as that scientific models should be explanatory, but are instantiated in specific examples, such as explanatory models of molecular motion that 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, following students identifying questions about phenomena, constructing models to explain their results, engaging in argumentation to evaluate, compare, refine their models through further investigations and develop a consensus model explaining the phenomena. These rich cases provide the context for active sensemaking and discussions of how teachers might foster similar engagement in their own classrooms.

Design principle 2. Focus PD on the high-leverage practices of argumentation, explanation, and modeling

There are many aspects of the reforms in the Framework and NGSS on which PD could focus. Studies of changes in teacher practice suggest the importance of focusing on "high-leverage practices" as instrumental in initiating change in teacher pedagogy (Ball et al., 2009; Smith & Stein, 2011; Windschitl, Thompson, Braaten, & Stroupe, 2012). High-leverage practices bring together critical kinds of learning that have high pay-off in the classroom. 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). Without progress on these, the shifts targeted in the Framework cannot occur. Furthermore, focusing on these three practices will help teachers consider how the conceptual work and discourse involved in explanation, argumentation, and modeling are not three independent learning goals. Supporting students in developing models requires understanding models as mechanistic explanations rather than descriptive accounts. Similarly supporting students in developing explanatory models requires argumentation to evaluate and compare competing accounts (Passmore & Svoboda, 2012; Schwarz, Reiser, Acher, Kenyon, & Fortus, 2012; Schwarz et al., 2009). In our PD system, videos of expert commentary, science tasks for teachers to perform, examples of student work, and video cases across a range of grade bands all involve developing, testing, and refining models that can explain phenomena, and engaging in argument from evidence to guide these processes.

Design principle 3. Organize teacher study groups working to apply the reforms to their own classroom practice

Teachers need more than presentations of ideas and strategies; they 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). In contrast to traditional one-shot workshops presenting educational topics, teachers need sufficient opportunities and support to apply the strategies to changes in their own practice (Darling-Hammond, 1995; Putnam & Borko, 2000). Teachers need to work together to analyze the reform ideas, and then plan, implement, and reflect on their incremental attempts to realize these ideas in their own classrooms.

In our PD system, this translates into opportunities to study examples of interaction that reflect a particular teaching and learning issue, such as how to support students in using argumentation to compare competing models. To support analysis and sensemaking, teachers work collaboratively to use what they are learning and explore how to make it work in their own classrooms. Discussions around specific examples of practice create opportunities for the analysis and debate needed to dig beneath the surface of the reforms, and to explore substantive issues in applying the reforms to practice (Sherin & Han, 2004; van Es & Sherin, 2008). These PD tasks, just as the nature of learning in NGSS, focus on knowledge-in-use rather than on abstract decontextualized knowledge. When working on science, student learning, or teaching issues, participants work together to connect what they are seeing to their own classroom experiences.

Design Principle 4. Help teachers connect what is new about the science, student thinking about the science, and pedagogical supports for the science

Changing classroom practice requires multiple strands of learning –addressing issues of student learning, curriculum and tasks, and teaching approaches (Ball & Cohen, 1999). Engaging teachers in analyses of student thinking is key in improving teaching practice (Borko, 2004; Putnam & Borko, 2000). Supporting learners in science practices requires helping students build on intuitive ideas and sensemaking practices and supporting them in incorporating more sophisticated disciplinary approaches (Schwarz et al., 2009). This requires understanding how science learning is fundamentally different with the commitment to building disciplinary knowledge through science practices, and requires being able to track student thinking and engagement in these practices in classroom interactions. Thus, effective PD needs to engage teacher learners in tasks with multiple lenses, focusing on (a) engagement with the disciplinary practices as learners, (b) analyzing students' engagement in these practices, and (c) focusing on pedagogical approaches to support these practices (Borko, 2004; Roth et al., 2011). In our PD system, participants develop, argue for, and refine explanatory models for phenomena exemplifying the target science (e.g., nature of matter), 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 5. Develop teacher leaders' 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 models of PD instruction, emphasizing content delivery by "experts." Instead, PD leaders need to engage in *knowledge-building facilitation* in which they strategically support participants in co-constructing new understandings with colleagues.

The work of facilitators in a co-construction PD model is to both model and guide figuring out how disciplinary content and high leverage practices come together, and developing the capacity for taking this knowledge back into participants' own classrooms. Teacher leaders of these PD contexts need preparation beyond learning about the reform; they need skills in orchestrating productive discussion among adults, and the pedagogical content knowledge 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 leadership development, *Facilitating Science Teacher Study Groups* Pathway is a course of study that prepares teacher leaders, PD providers, and other instructional leaders to become expert facilitators of teacher study groups. Using tasks, tools, and resources embedded in the PD web platform this pathway is designed to help would-be teacher leaders actively engage in creating and sustaining a learning community focused on 3-dimensional science.

In the next two sections, we present the two NGSX pathways based on these design approaches and used in the current empirical study of the scale-up of PD.

The Introduction to Three-Dimensional Science Learning Pathway

In the Introduction to 3D learning pathway, teachers' work with science investigations as learners interwoven with analyses of classroom cases provide experience in understanding how science practices can help their students develop, apply, and refine disciplinary and crosscutting ideas. Through a series of seven units, comprising about 45 hours of sessions, 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. Pathway examples of practice focus on the practices of argumentation, explanation, and modeling, situated in the context of investigations of matter. The pathway units are summarized in Table 2.

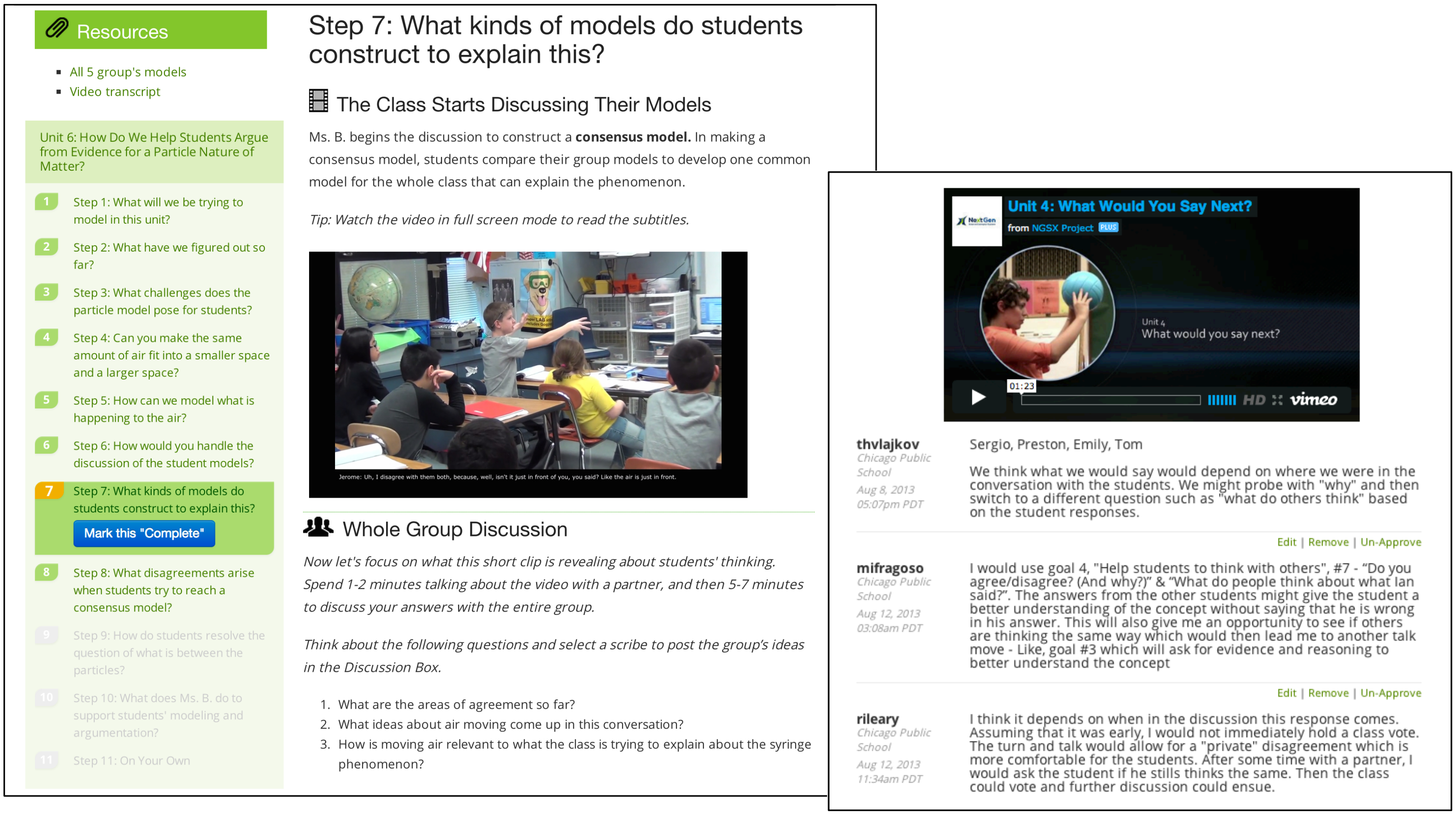
Table 2. The NGSX pathway introducing three-dimensional learning

	Unit	Unit foci	Perspectives
1	*How do we develop and use models?*	Developing and using models to explain matter phenomena Connecting the experience to key shifts in the Framework	Experience 3D learning Pedagogy for 3D learning
2	*How can we evaluate and revise models based on evidence?*	Revising models based on evidence Identifying key characteristics of science practices	Experience 3D learning Pedagogy for 3D learning
3	*How does discussion support argumentation, explanation, and modeling?*	Analyzing practices in classroom discussion Updating model of science practices	Investigating 3D Student learning Pedagogy for 3D learning
4	*How do we build a classroom culture that supports public reasoning?*	Analyzing talk moves in classroom discussions	Investigating 3D Student learning Pedagogy for 3D learning
5	*How do we help student argue from evidence for a particle model of matter?*	Analyzing a middle school classroom case of students developing models to explain air phenomena	Investigating 3D Student learning Pedagogy for 3D learning
6	*What types of tools help students refine models over time and develop deep explanations of science phenomena?*	Analyzing a high school classroom case of students engaging in argumentation to model air pressure phenomena	Investigating 3D Student learning Pedagogy for 3D learning

7	*How do we bring three-dimensional learning into our own classrooms?*	Integrating science practices to adapt existing instructional units	Pedagogy for 3D learning

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 engage during these three units from two perspectives. First, they develop the disciplinary core ideas through science practices as they participate as learners. Second, they consider the shifts in pedagogy 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 that can support argumentation, explanation, and modeling. In units 5-6, participants study middle and high school classrooms through in-depth analyses of video cases. Their developing understanding of the practices and subject matter becomes a basis for exploring the instructional and pedagogical decisions and structures one must have in place to support students in learning science through participation in the practices. The three-day unit 7 focuses on an NGSS storyline approach, involving unpacking disciplinary core ideas, identifying aligned phenomena and questions, and developing coherent NGSS storylines at the participants' own grade band, in which learners investigate phenomena through science practices to incrementally develop and use disciplinary core ideas.

In a typical session, a study group of 15-20 teachers meets for three to five hours. Participants login to the online system. The facilitator has his or her laptop connected to a projector for the group to view video and task prompts embedded in the site. An introductory video from one of the online guides (a teacher, scientist, or researcher) introduces the theme for the unit, such as the nature of modeling, support for classroom discourse, or difficulties students face in reasoning about the nature of matter. Many units include classroom cases to analyze, typically consisting of a series of short five min clips of teachers and students engaged in modeling practices, followed by prompts for discussion (see Figure 1A) that focus on modeling tasks, student thinking, or teaching strategies. Participants consider how the student work and teaching supports reflect the vision of the Framework, and may diverge from common classroom practice. The facilitator may summarize the conclusions of the whole study group or teachers may discuss and enter their responses in small groups (see Figure 1B). The unit concludes with work to do 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.



- All 5 group's models
- Video transcript

Unit 6: How Do We Help Students Argue from Evidence for a Particle Nature of Matter?

1 Step 1: What will we be trying to model in this unit?
2 Step 2: What have we figured out so far?
3 Step 3: What challenges does the particle model pose for students?
4 Step 4: Can you make the same amount of air fit into a smaller space and a larger space?
5 Step 5: How can we model what is happening to the air?
6 Step 6: How would you handle the discussion of the student models?
7 Step 7: What kinds of models do students construct to explain this?
8 Step 8: What disagreements arise when students try to reach a consensus model?
9 Step 9: How do students resolve the question of what is between the particles?
10 Step 10: What does Ms. B. do to support students' modeling and argumentation?
11 Step 11: On Your Own

Step 7: What kinds of models do students construct to explain this?

The Class Starts Discussing Their Models

Ms. B. begins the discussion to construct a **consensus model.** In making a consensus model, students compare their group models to develop one common model for the whole class that can explain the phenomenon.

Tip: Watch the video in full screen mode to read the subtitles.

Jerome: Uh, I disagree with them both, because, well, isn't it just in front of you, you said? Like the air is just in front.

Whole Group Discussion

Now let's focus on what this short clip is revealing about students' thinking. Spend 1-2 minutes talking about the video with a partner, and then 5-7 minutes to discuss your answers with the entire group.

Think about the following questions and select a scribe to post the group's ideas in the Discussion Box.

1. What are the areas of agreement so far?
2. What ideas about air moving come up in this conversation?
3. How is moving air relevant to what the class is trying to explain about the syringe phenomenon?

thvlajkov
Chicago Public School
Aug 8, 2013 05:07pm PDT

Sergio, Preston, Emily, Tom

We think what we would say would depend on where we were in the conversation with the students. We might probe with "why" and then switch to a different question such as "what do others think" based on the student responses.

mifragoso
Chicago Public School
Aug 12, 2013 03:08am PDT

I would use goal 4, "Help students to think with others", #7 - "Do you agree/disagree? (And why?)" & "What do people think about what Ian said?". The answers from the other students might give the student a better understanding of the concept without saying that he is wrong in his answer. This will also give me an opportunity to see if others are thinking the same way which would then lead me to another talk move - Like, goal #3 which will ask for evidence and reasoning to better understand the concept

rileary
Chicago Public School
Aug 12, 2013 11:34am PDT

I think it depends on when in the discussion this response comes. Assuming that it was early, I would not immediately hold a class vote. The turn and talk would allow for a "private" disagreement which is more comfortable for the students. After some time with a partner, I would ask the student if he stills thinks the same. Then the class could vote and further discussion could ensue.

Figure 1. Example steps from the Introduction to Three Dimensional Learning Pathway
A (left): A step from a unit (Unit 5) supporting teachers in analyzing classroom interactions. 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.
B (right): The task asks teachers to consider how they would respond to particular student ideas in a discussion. (From Unit 4 on classroom discourse that supports science practices.)

The Facilitator Pathway for Three-Dimensional Science Learning

The *Facilitator Pathway* is 24-hour course of professional learning organized into five chapters, each typically 3-4 hours in length, and occur interwoven within the Intro to 3D learning pathway units. They are designed to support work on three critical facets of facilitating teacher study groups: *Productive Knowledge-Building, Culture-Building Strategies,* and *Pedagogical Content Knowledge for Facilitators*. These are not discrete lines of knowledge or ways of thinking about facilitation, but rather, mutually reinforcing domains of knowledge and skills necessary to support a PD model focused on 3D learning and teaching of science.

The pathway addresses the following goals for productive knowledge building:

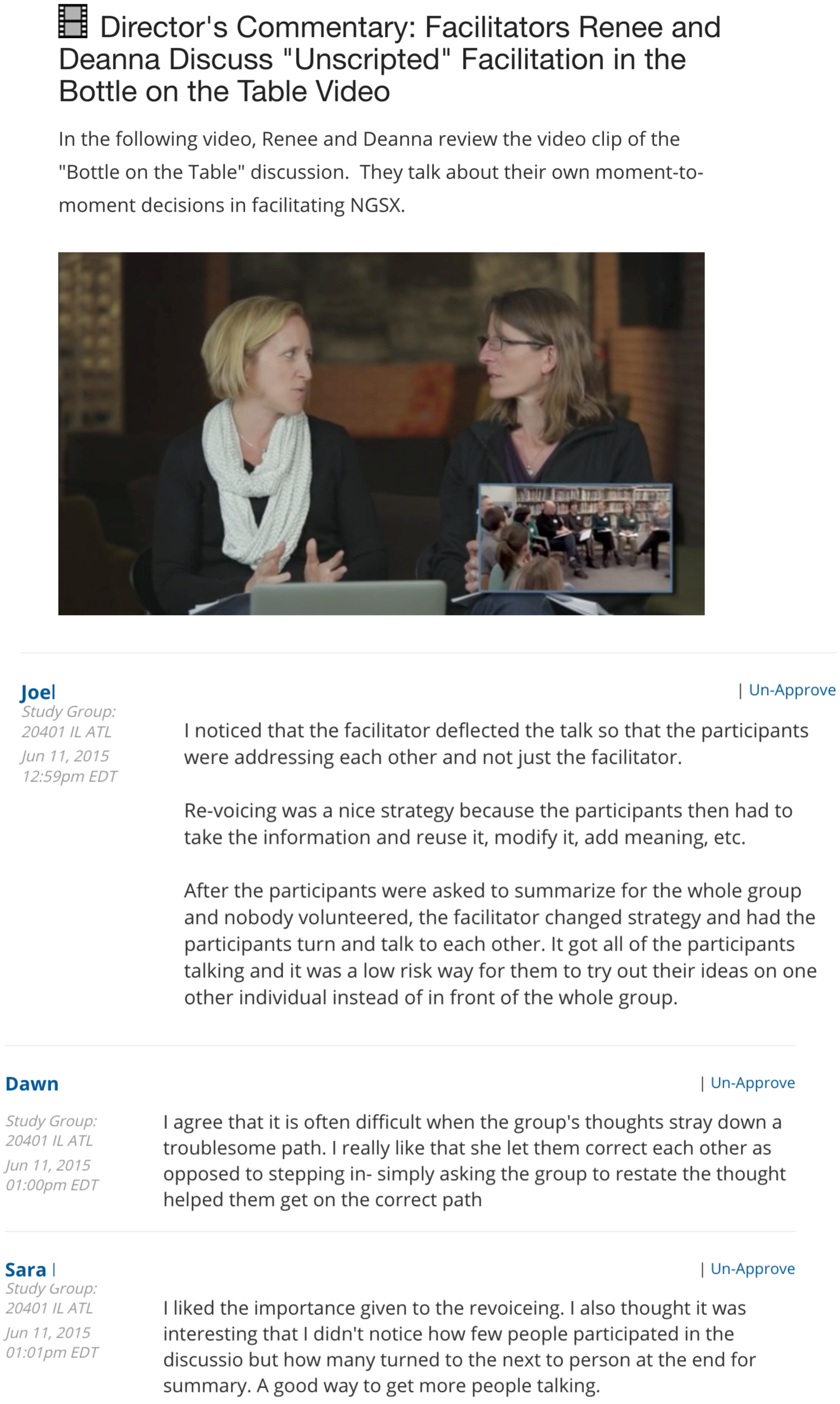
- Helping study group participants go public with their arguments and explanations of phenomena, and work on model building.
- Building capacity among participants to listen to and take one another seriously as thinkers and learners of science, and as investigators of their own teaching practice, students, and classroom.

- Helping participants dig deeper into modeling, argumentation, and explanation, and persist when confusion arises or when their understandings remain partial or fragile.
- Knowing how to motivate and guide participants in co-constructing explanations of phenomena with other study group participants, incorporate others' ideas into their own thinking, and progressively building disciplinary core ideas.
- Positioning oneself as a peer in a sensemaking process — as a member of the group, as a learner, and not as an all-knowing expert.

Using Culture-Building Strategies requires a facilitator to know how to establish and sustain study group norms on respect, risk-taking, equity, and collaboration. The goal is to create a learning community among science educators, in which knowledge-building can happen for everyone, regardless of grade-level, science background or knowledge of the Framework and NGSS. The culture building strategies include effectively working with different levels of science content knowledge and familiarity with the Framework.

Pedagogical-Content Knowledge (PCK) for facilitators focuses on strategies for helping participants build facility with the cores teaching shifts involved in three-dimensional science learning. This includes work with the challenges teachers face in using practices to support their students' learning, in unpacking disciplinary core ideas to see how they can help students to build them incrementally over time, knowledge of how to identify curriculum materials that can support students' three-dimensional learning, and how to help study group participants go beyond description to detailed analyses of classroom interactions in video-based cases.

For example, the Facilitator Pathway uses a device called a "Director's Commentary" in which two skilled facilitators engage in a moment by moment analysis of what is unfolding in a discussion of a study group. The participants first watch the study group clip and discuss it, and then see the two experienced facilitators debrief about the clip they have just watched. They "would be" facilitators are viewing the actual study group episode. An example of several participants' reflections following the director's commentary is shown in Figure 2.



Director's Commentary: Facilitators Renee and Deanna Discuss "Unscripted" Facilitation in the Bottle on the Table Video

In the following video, Renee and Deanna review the video clip of the "Bottle on the Table" discussion. They talk about their own moment-to-moment decisions in facilitating NGSX.

Joel
Study Group: 20401 IL ATL
Jun 11, 2015 12:59pm EDT

| Un-Approve

I noticed that the facilitator deflected the talk so that the participants were addressing each other and not just the facilitator.

Re-voicing was a nice strategy because the participants then had to take the information and reuse it, modify it, add meaning, etc.

After the participants were asked to summarize for the whole group and nobody volunteered, the facilitator changed strategy and had the participants turn and talk to each other. It got all of the participants talking and it was a low risk way for them to try out their ideas on one other individual instead of in front of the whole group.

Dawn
Study Group: 20401 IL ATL
Jun 11, 2015 01:00pm EDT

| Un-Approve

I agree that it is often difficult when the group's thoughts stray down a troublesome path. I really like that she let them correct each other as opposed to stepping in- simply asking the group to restate the thought helped them get on the correct path

Sara
Study Group: 20401 IL ATL
Jun 11, 2015 01:01pm EDT

| Un-Approve

I liked the importance given to the revoiceing. I also thought it was interesting that I didn't notice how few people participated in the discussio but how many turned to the next to person at the end for summary. A good way to get more people talking.

Figure 2. Reflection on episodes of facilitation in the Facilitating Teacher Study Groups pathway

The PD program design

This study examines the use of the practice-based professional learning model in an effort to scale up professional development across a Midwestern state that includes a major urban center, suburbs, and rural areas. The program was selected for 2015 to be the science professional development 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/ MSP funds are dispersed within a state through a competitive process utilizing a Request for Proposal designed and managed by the state's department of education. MSP projects generally provide teachers with 80 contact hours of professional development in the summer, and four follow up days in the following academic year.

The State MSP PD program was implemented in two phases. The first RFP (9/16/15) requested applications for a Lead Partnership (LP) that would manage the PD Network. A subsequent RFP (2/13/15) requested proposals for up to 11 regional partnerships known as Science Area Partnerships (SAPs). The 11 SAPs were distributed among the six geographical regions of the state. The SAP were tasked with recruiting at least 20 K-8 teachers and 20 9-12 teachers in order to qualify for funding. Partnerships were defined including included a science, math, or engineering institution of higher education, a high-need local education agency, a Regional Office of Education to serve as the fiscal agent; and a business or non-profit organization with demonstrated effectiveness in improving the quality of science or mathematics teachers.

The program was implemented in the summer of 2015. The state agency awarded a Lead Partnership and 11 regional partnerships from across the state, including two partnerships from the urban center. The lead partnership selected 24 Area Teacher Leaders (ATLs). In phase I, the project's team of lead facilitators worked with the 24 ATLs for 10 days across three weeks, using the Introduction to 3D Learning and Facilitating Teacher Study Groups pathways.

Phase II followed approximately two weeks later, in which Area Teacher Leaders each led a study group for nine days (across three weeks) through the Introduction to Three-dimensional Learning pathway. The 24 ATLs led 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.

In this paper, we present analyses of the growth for the teacher participants in the area partnerships. Our questions examine the effectiveness of the scale-up phase of this work, in which teacher leaders worked with participants to help them learn about 3D science learning, guided by what they learned about knowledge building facilitation. We investigated three research questions about the effects of science PD focused on classroom practice:

1. How does PD focused on classroom practice help teachers improve their proficiency with three-dimensional science?

2. How does PD focused on classroom practice influence teachers' shift in beliefs about learning and teaching that support 3D learning?
3. How does PD focused on classroom practice help teachers develop pedagogical content knowledge that supports 3D learning?

Methods

The data for teacher growth comes from online surveys given at the beginning and end of the professional development. The pre-survey was administered online through a link sent via email to all participants one week prior to the start of the PD. The post survey was administered during the last day of the PD. Of the 420 teachers completing the PD, 241 (57%) of all participants consented to be a part of the research. Teachers were not compensated for participating in the research activities. All data, analysis, and results presented in the following sections are from this group of teachers. 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.

The surveys included sections to tap teachers' ability to engage in 3D science reasoning, their attitudes and beliefs across a range of teaching issues, their instructional goals, and measures of their ideas about science practices. Items about instructional preparedness, instructional goals, and beliefs were selected from the 2012 National Survey of Science and Mathematics Education (Banilower et al., 2013). The remaining items were developed specifically for this project, and have been pilot tested with over 300 teachers participating in earlier versions of the PD. (The full set of items are shown in Appendix A.). The following categories of items were used on both the pre and post survey:

3D Science Learning: These items measured teachers' proficiency in developing explanations of phenomena involving the particle nature of matter and included six multiple choice items and one constructed response item:

> *Explain as best you can in the space below, in nontechnical everyday language how a vacuum cleaner works to pick up dirt. What makes the dirt go into the vacuum cleaner?*

Confidence with the Framework and NGSS: These 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 five point scale from *unfamiliar* to *very confident*.

Preparedness to Incorporate Science and Engineering Practices: These items asked teachers to rate each of eight science and engineering practices on a 4 point scale on the question "how well prepared do you feel to support students in each of the following science and engineering practices?"

General Instructional Preparedness: These items asked teachers to rate how prepared they feel for particular instructional tasks, such as *anticipate difficulties that students may have with particular science ideas and procedures.*

Reform-Oriented Instructional Goals: These items asked teachers to rate the emphasis they plan to give particular instructional goals consistent with the Framework and NGSS, such as *understanding science concepts* and *increasing students' interests in science.*

Beliefs about Teaching and Learning: These items asked teachers to rate their agreement on a 6 point scale with various statements about teaching and learning. Some articulated beliefs more consistent with traditional instruction (e.g., *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*), while others were more consistent with the shifts in the Framework and NGSS (e.g., *Students should use evidence to evaluate claims about a science concept made by other students*). We developed three composite scores from the individual belief questions (see Analysis section).

Pedagogical Content Knowledge for Science Practices: Several constructed-response items were included that asked teachers to describe good examples of classroom activities that engage students in developing and using models (Modeling), argument from evidence (Argumentation), and whole-class science discussions (Discourse). These items were designed to assess what teachers understood about how to use these science practices in classroom settings, thus assessing a key aspect of pedagogical content knowledge needed to bring these practices into classrooms (refs PCK book). Only responses from the modeling questions will be presented in this paper.

In addition to these items, the pre-survey also asked teachers closed-ended items about the frequency with which they use different instructional activities (from Banilower et al. 2013), 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 1-2 most important things they learned during the PD.

Participants

A total of 420 participants were selected by the 11 science area partnerships. The participants were all teachers of science at the K-12 level, including some generalist teachers, such as elementary teachers and special education teachers, as well as specialist teachers that only teach science. An additional 16 teachers were planning to attend the PD, but dropped prior to the first session. These teachers are not included in the numbers of participants. There was no attrition during the 10-day training (i.e. all participants that started the PD finished).

Each Science Area Partnership acted as PD site and coordinated selecting teachers for the program. Ten of the 11 sites split teachers into two groups. These groups were picked by the facilitators and site staff to ensure an equal distribution of grade levels across the two groups and to be sensitive to inter-personal relationships that might affect the collaborative learning environment of the PD, as well as networking opportunities. In total, 21 different groups implemented the PD, with group sizes of eight to 32 participants.

Recruitment of teachers to participate in the NGSX PD was designed to get equal distribution across the K-12 spectrum. The teachers in the NGSX Professional Development were fairly well distributed across the K-12 spectrum, as shown in Table 3, although there were fewer middle school teachers. The PD goals ranked as most important by teachers were (1) to learn how to adapt their teaching to be aligned with NGSS (35%), and (2) 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 goal for participating.

Table 3: Teaching position of participants in the PD

	N	Percent
All Current Teaching Position(s)		
Elementary	85	35.7%
Middle School	64	26.2%
High School Science (all)	89	36.9%
HS Biology	53	22.1%
HS Chemistry	45	18.9%
HS Physics or Physical Science	42	17.6%
HS Earth Science	29	11.9%
HS Environmental Science	14	5.7%
Special Education	7	2.9%
Did not Respond	15	6.1%
Highest Grade Band Taught		
Elementary	79	32.8%
Middle School	58	23.8%
High School	89	36.9%
Did not Respond	15	6.1%

Analysis

The analysis of the data focused on investigating pre-post impact across the different outcome measures, as well as exploring whether these impacts seemed to vary between different groups completing the PD.

Constructed-Response Scoring and Coding. Several constructed-response items were either qualitatively coded or scored. In this paper we scored the constructed-response science content item about explaining how a vacuum cleaner works, while items about describing an example modeling activity and teachers' most important learning from the PD were coded qualitatively. These coding schemes are described in the results sections for each type of measure.

Most Important Learning from PD Coding. Categories of similar topics mentioned in responses about teachers' most important learning from the PD were created through open-coding. Seven categories were identified: discourse/argumentation, phenomena-driven lessons, discover-based learning, student-driven classrooms, storyline development, teacher moves/teacher role, unpacking the NGSS/3D learning. Teachers' responses were coded for the presence of each of the codes, and as such, teachers' responses could show evidence of more than one code.

Constructing Composite Quantitative Measures. We developed composite scores to group related items into clusters for each domain measured quantitatively on the pre- and post-survey. Each scale or group of items was developed through pilot testing, and was tested using confirmatory factor analysis with data from the current group of participants. The previously-developed item groupings fit the NGSX PD data well. The component elements of each composite is shown in Appendix A. The composite scales are:

- *3D Science Learning Composite*: A composite of the constructed response and multiple choice items.
- *Preparedness to Incorporate Science and Engineering Practices*: A composite of how prepared teachers judged themselves to incorporate each of the eight science and engineer practices into their classroom teaching.
- *General Instructional Preparedness*: A cluster of six items reflecting general aspects of teaching that are not specific to the Framework and NGSS, such as "monitor student understanding" and "implement prescribed lesson plans."
- *Reform-Oriented Instructional Goals:* A cluster of five areas rated for "how much emphasis will each receive in your classroom" that are generally consistent with the science reforms of the 1990s through NGSS, including understanding science concepts," "increasing students' interest in science" and "learning about real-life applications of science."
- *Beliefs about Traditional Instruction*: A cluster of eight teacher belief items that addressed traditional teaching approaches typically identified with traditional teaching that are 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*: A cluster of five belief items that refer 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*: A cluster of six belief items that refer 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."

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 from the current study scaled together.

Analyses of Pre-Post Impact. We analyzed pre-post impact through matched-pair t-tests on the seven composites. Wilcoxon Signed-rank tests were completed on the two items about teachers' confidence in implementing the framework and NGSS, as well as the model purpose coding. Due to multiple tests, a Bonferroni correction was used for an effective significance level of .005 for these 10 primary effects that were tested. To explore changes on individual items within the composites, a Wilcoxon matched-pairs signed-ranks tests was completed for items with an ordinal scale, while a two-proportion z-test was completed for binary items. Effect size was computed for all statistically significant differences on the composites using Cohen's d. For individual items, effect sizes were computed using Cliff's delta for items with an ordinal scale and with Cohen's h for binary items. All pre-post impact tests were completed in STATA.

Analysis of Differences in Impact by Group and Teaching Position: As the PD was implemented in 21 different study groups and with teachers across the K-12 spectrum, we explored differences in the impact across these different types and groups of teachers. One-way ANCOVA was used for each composite score to test for differences. The pre-score for each composite was entered as the covariate to investigate whether there were differences by group in the pre-post change on the composites rather than simply the post-scores. Each composite domain was tested separately, and different models were run to look for differences between study groups and teacher's grade level taught.

For models examining differences by teachers' grade level, we conducted post hoc analyses when statistically significant differences were found using Tukey's honestly significant difference (HSD). This analysis of between group differences was more exploratory to see if study group teacher related to differences in the PD's effectiveness. The study design did not include the appropriate sample size with which to test for differences robustly. Therefore, we only report pre-post impact for each group at a significance level of .05 with no corrections for multiple post-hoc tests.

Results and Discussion

We evaluated the impact of the PD program on multiple aspects of the teachers' knowledge, perception of readiness for NGSS, and beliefs about teaching and learning science. In successive sections we examine (a) three-dimensional science learning; (b) confidence with the Framework and NGSS; (c) emphasis on reform oriented instructional goals; (d) preparedness for instruction; (e) beliefs about teaching and learning science; and (f) pedagogical content knowledge for modeling practice. We also examined teachers' self report of what they learned and present examples where they help elaborate on the suggested quantitative shifts.

Teachers' Three-Dimensional Science Learning

The 3D Science Learning items assessed teachers' ability to address explanatory and modeling questions about the behavior of matter. We developed and refined a scoring rubric for the vacuum cleaner question based on pilot data. The scale examined the degree of mechanism in participants' explanations, and captured a shift from intuitive ideas about vacuums "sucking" or "pulling" to a more mechanistic account involving molecules in movement that collide and push one another. The scoring guide along with sample responses is given in Appendix B. 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 researcher trained in the scoring rubric scored 12% of the responses, with a Cohen's kappa of .73. We combined score for each teachers' constructed response item with their multiple choice 3D science learning questions to develop a composite 3D science learning score.

Teachers' 3D science learning scores increased dramatically from pretest to posttest, 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 posttest. The large effect size indicates a large gain in teachers' science learning about the nature of matter.

While the goals of the PD go beyond teachers simply "learning the science," a number of activities to tease apart the key shifts in the Framework and NGSS rely on teachers' own experiences grappling with the science. For example, teachers worked on "indicator lists" of the practices of argumentation, explanation, and modeling. These indicators reflected what one would see teachers and students doing when engaged in these practices, and were intended to help teachers flesh out intuitive ideas of inquiry to specify more clearly how knowledge building practices can take place in classrooms. Teachers began these indicator lists by reflecting on their own experience in Units 1 and 2 developing models to explain the behavior of matter, and built upon them as they added a focus on discourse (Unit 4), and saw middle and high school students engaged in these practices (Units 5-6). Thus, establishing that teachers came away with an increased ability to engage in modeling, explanation, and argument in the context of matter establishes this important prerequisite for the deeper learning about student thinking and pedagogy.

Consistent with this, some teachers commented on the importance of their own experience with learning involving the science practices for understanding the shifts in teaching with NGSS. For example, one teacher wrote, "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." In this response the teacher draws on his or her experiences developing rather than being told the model or being told with is wrong with her intuitive ideas (about suction).

Change in Teachers' Reported Confidence With the Framework and NGSS

Teachers reported an increase in confidence in teaching science in the ways called for by the NRC Framework and NGSS. The median responses for confidence level shifted from *somewhat confident* to *confident* for teachers' judgments for both the Framework and 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. Figure 3a and 3b show the distribution of responses on both the pre- and post-survey, showing that prior to PD many teachers were unfamiliar or not very confident, with a majority shifting to *somewhat confident* or *confident* after the PD.

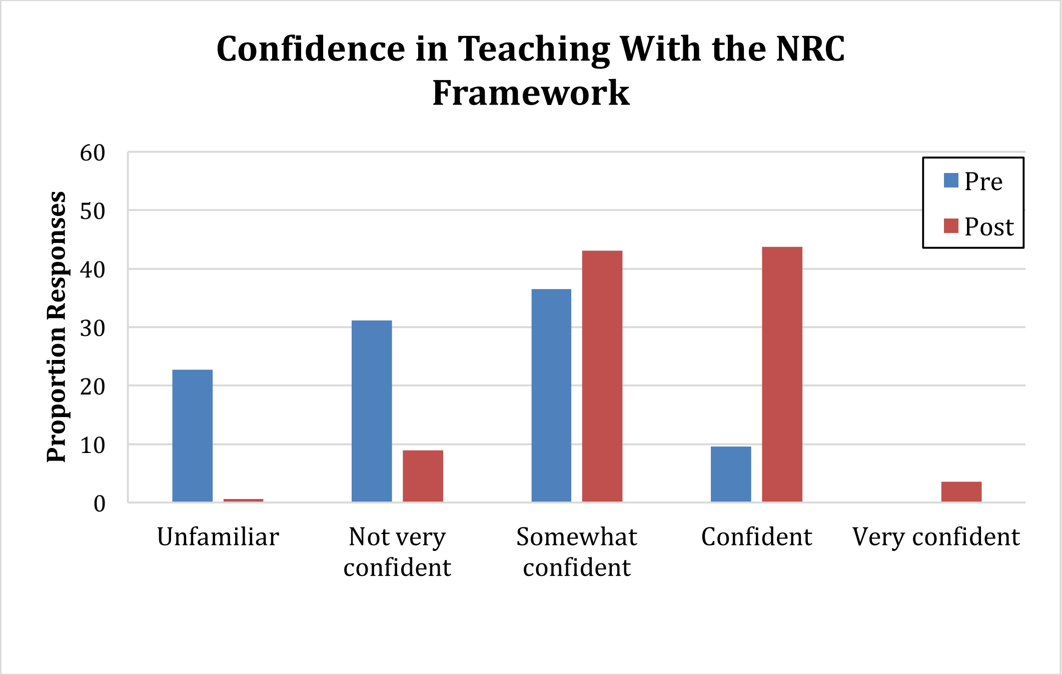


Figure 3a. Teachers rated confidence in "teaching in ways called for in the Framework."

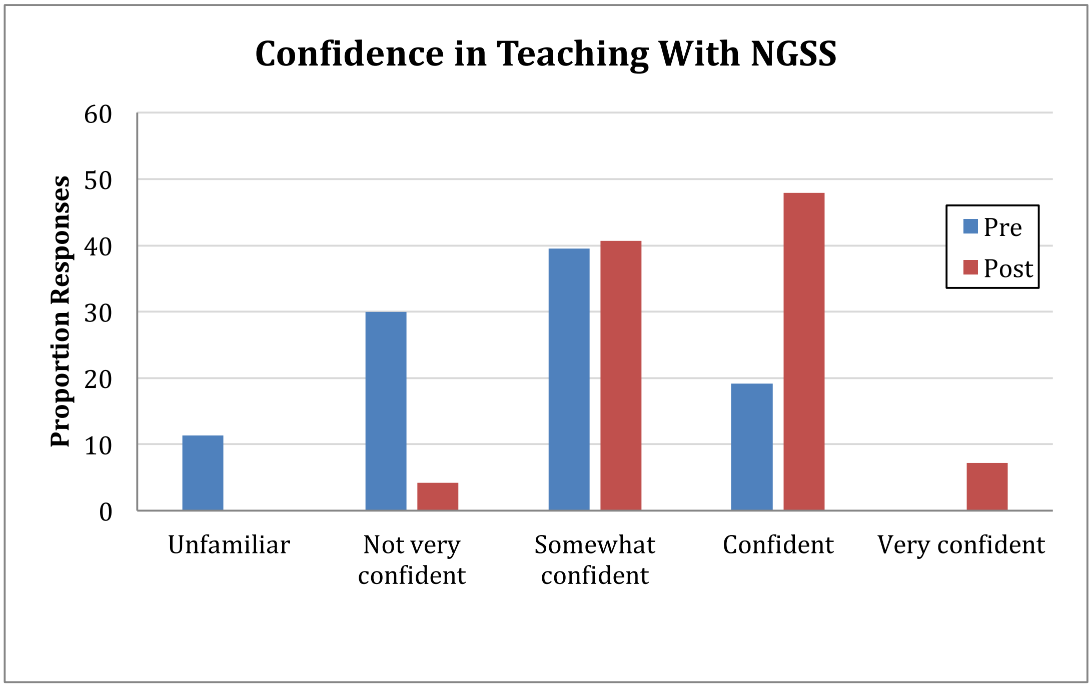


Figure 3b. Teachers rated confidence in "teaching in ways called for in NGSS."

Table 4 summarizes the quantitative composite measures concerning teachers' judgments about their goals, preparedness, and beliefs used in the next three sections.

Table 4. Impact of the PD on Teachers' Goals, Preparedness, and Beliefs

	N	**Mean Pre**	**Mean Post**	**Std. Error**	**Effect Size**	***t*-value**	**df**	***p*-value**
Reform-Oriented Instructional Goals	168	-0.24	0.17	0.07	0.38	5.93	167	<0.001
General Instructional Preparedness	169	-0.20	0.25	0.10	0.29	4.29	168	<0.001
Preparedness To Incorporate Science and Engineering Practices	169	-0.43	0.59	0.11	0.59	9.52	168	<0.001
Beliefs about Traditional Instruction	169	0.33	-0.38	0.06	-0.68	-11.50	168	<0.001
Beliefs about Students Engaging with Evidence	169	-0.05	0.17	0.05	0.25	4.23	168	<0.001
Beliefs about Using Student Ideas in Instruction	168	-0.05	-0.01	0.06	NA	0.70	167	0.486

Teachers' Planed Emphases on Reform 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, 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, the agendas for the PD did connect with these ideas somewhat as part of the teachers' work on the Framework and NGSS, so it is perhaps not surprising that teachers reported expecting to give these goals more emphasis following the PD.

Change in Teachers' instructional Preparedness

The next set of items asked how prepared teachers felt for a set of 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 the eight science 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 preparedness results, along with the increases in teachers' reported confidence, indicate that teachers feel more prepared to implement the new standards in their classrooms. For example, one teacher wrote, "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." In this response, we see the connections that the teachers made between argumentation and developing science understanding that was reflected in many of the responses. In fact, over one third of teachers' responses to the most important thing they learned in the PD mentioned argumentation, discussion, or talk moves, many of them explicitly connecting these strategies to helping students develop explanations of scientific phenomena. For example, one teacher said, "Productive talk is what we need to move toward where students feed off of others ideas in the classroom." In this way, the PD seemed to be successful in helping teachers see how engaging students in discussion and argumentation can be a means to helping students develop scientific understanding in ways aligned with the new standards.

Change in Beliefs about Teaching and Learning Science

While the self-reported measures changes in confidence, preparedness, and goals are encouraging, for the PD to be successful in eventually influencing the teachers' classroom practice it must affect what teachers understand, believe, and have learned about the classroom. So far we found teachers improved in one area of 3D science. In this section and those that follow, we examine potential shifts in the beliefs that may influence teachers' ability to implement the Framework and NGSS, and their understandings of NGSS in the classroom.

Of particular interest is the composite belief measure concerning beliefs about traditional instruction. The 2012 national survey of science teachers uncovered a number of widely held beliefs that are somewhat in opposition to the pedagogical approaches required to teach with science practices (Banilower et al., 2013). Table 5 lists the items included in the Traditional Beliefs composite, and our arguments about why the Framework and NGSS are in conflict.

Table 5. Conflicts between beliefs about instruction and 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 disciplinary core ideas (DCIs). Hands-on science doesn't necessarily build DCIs unless students are challenged to apply what they are observing about phenomena to the DCIs.
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*	The point of science activities is to develop evidence about phenomena so they can build the ideas by making sense of that evidence. Known-outcome experiments usurp the

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.*	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 should not be 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 should be building explanations and models that use the disciplinary core ideas. Vocabulary is useful for aiding in precision in articulating ideas, but vocabulary items themselves are not the goals. Vocabulary should be grounded on understanding the ideas. Pre-teaching vocabulary before helping students develop the ideas does not support students' development of those ideas.

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 .68. Thus, the PD appears to have influenced some of these traditional views that could be at odds with implementing NGSS. Responses about what teachers learned in PD were consistent with this and referred explicitly to changes in their own thinking. Here are several examples:

> *How to correctly read the new standards and 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 phenomena 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 understand the standards better. 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.*

We next examined the second cluster of beliefs items, which 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 Appendix A). 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 cluster of belief items examined various statements about connecting student and scientific ideas. While broadly consistent with the intent of the Framework and NGSS, these statements generally reflected views of good pedagogy, and were not novel 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.

Change in Teachers’ Pedagogical Content Knowledge about Modeling

Key to the professional learning approach is connecting what teachers are learning to their own classroom practices. While it was not possible in this study to follow the teachers into their own classrooms, we endeavored to get a preliminary index of their readiness to do so by asking teachers to describe classroom scenarios they felt reflected use of particular science practices. For this paper, we focused on teachers’ responses to the questions about modeling. Supporting the practice of developing and using models presents real challenges for teachers, who have limited experience with helping students build conceptual models that explain phenomena (Henze, Van Driel, & Verloop, 2007; Justi & Gilbert, 2002). To investigate what teachers learned about this practice, 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 modeling items together along two dimensions: (a) the purpose of the modeling activity, and (b) the type of model involved. We developed the coding scheme for teachers’ stated purpose of the modeling drawing on the literature on teachers’ conceptions and approach to modeling (Henze et al., 2007; Justi & Gilbert, 2002; Van Driel & Verloop, 1999). These categories included “activity for activity’s sake”, “demonstration”, and “explaining and predicting”. These categories were further refined through analyzing a pilot data set, resulting in the categories in Table 6. We developed the codes for the type of model based on prior modeling literature (Berland et al., 2015; Passmore et al., 2014; Passmore & Svoboda, 2012; Schwarz et al., 2009; Schwarz & White, 2005) combined with inductively defined emerging categories (see Table 7).

Table 6. Coding Scheme for Model Purpose in Example Modeling Activity Responses

Code	**Levels and Description**	**Sample Responses**
Unspecified or Non-Science Instructional Goals	Level 0: General classroom/school goals not related to science	*The purpose of students developing models is to solidify knowledge and utilize (kinesthetically) higher order thinking skills in order to engage, promote and encourage connections.*
Practice a Skill or Activity for Activity's Sake	Level 1: To practice a method, a technical skill, or becoming familiar with a particular 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. Learning about a set of materials or completing a challenge, but unclear if there is a learning goal beyond that.	*We create a Rube Goldberg model where the students have to use at least 5 steps to result in breaking an egg, or some other things......they understand how things work better*
Demonstrate or Introduce a Concept	Level 3: Explore to introduce or apply. To introduce new concepts to students or to better understand already known information. Illustrate or demonstrate principles.	*The students were asked to construct a model that shows 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.*
Develop New Knowledge	Level 4: Using known information to design or predict what will happen in a new specific situation or 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 have 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: To develop new knowledge that is general or is intended to be generalized. Students developed the model/knowledge/system and thus have the agency to revise or modify as they go.	*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 waves could build on each other creating amplitude.*

Table 7. 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 5 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.*

We coded teachers' responses to the example modeling activity for the type of model and purpose. We grouped responses to the three questions together, de-identified and blinded them with respect to pre- or post-response prior to coding. A second researcher trained in the coding scheme scored 24% of the responses, with a Cohen's kappa of .8 for model type and .69 for model purpose.

In teachers' responses to these modeling questions, we found changes in teachers' understanding of the use of modeling in the classroom. Figure 4 presents the shift in teachers' conceptions for the purpose of a modeling activity. Following the PD, we saw fewer responses where the model connected to disciplinary core idea learning goals (levels 0-2) and using a model to show an idea so that students can see it in action (level 3), and an increased frequency of cases where the models are generative, and used to develop specific solutions or new predictions (level 4) and to develop new general knowledge (level 5). A Wilcoxon Signed-ranks 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), $Z = 3.78$, $p = .0002$. Calculating Cliff's delta, we find an effect size of .29, indicating a small positive effect.

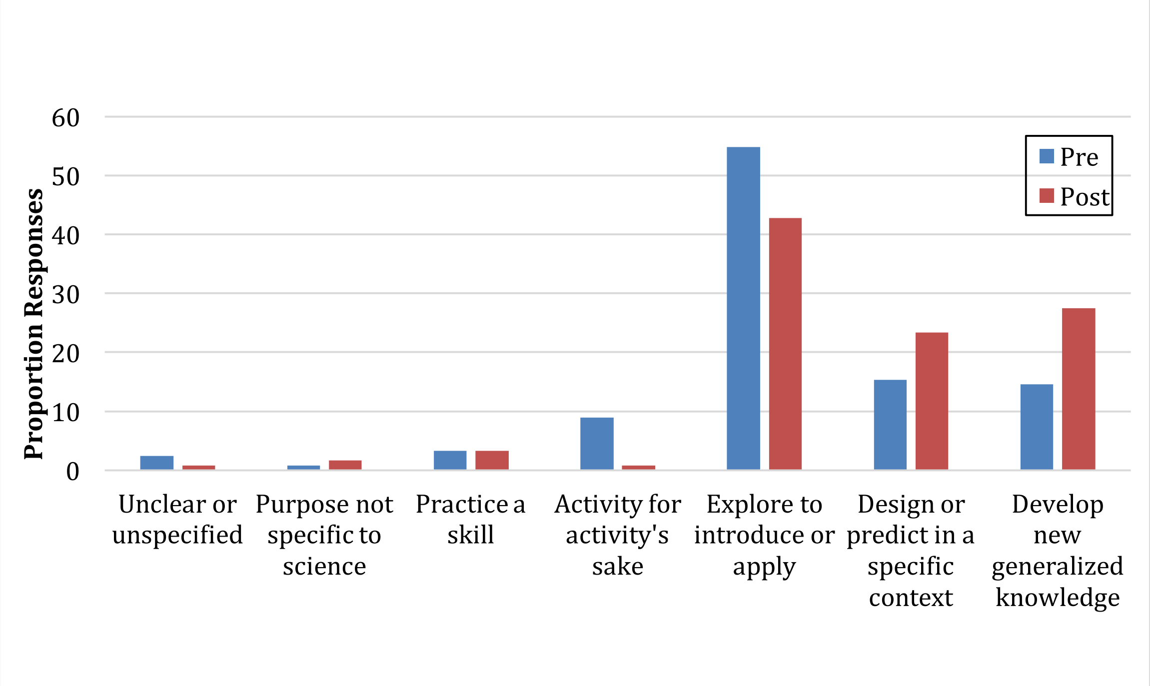


Figure 4. Shifts in the purpose teachers attributed to scenarios they described as good examples of the practice of developing and using models

This shift from models as demonstrations and as ways for students to see ideas they have been taught to a view where models are generative, and ways for students to develop new ideas, is critical to more sophisticated views of the developing and using models practice (Berland et al., 2015; Schwarz et al., 2009; Schwarz & White, 2005). This approach to modeling is key to the knowledge building practices of the Framework and NGSS into classrooms.

Next we examined the types of models. 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 are constructing a physical model or are developing a conceptual model. Approximately 22% and 26% of responses fell into this category on the pretest and posttest respectively. We also found five categories 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 teachers' described modeling activities. In those cases where it is possible to discern the type of model, we see a decreased focus on models as physical constructions, and an increased focus on models as abstract representations, such as diagrams showing molecular movement or forces. These types of abstract models are 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).

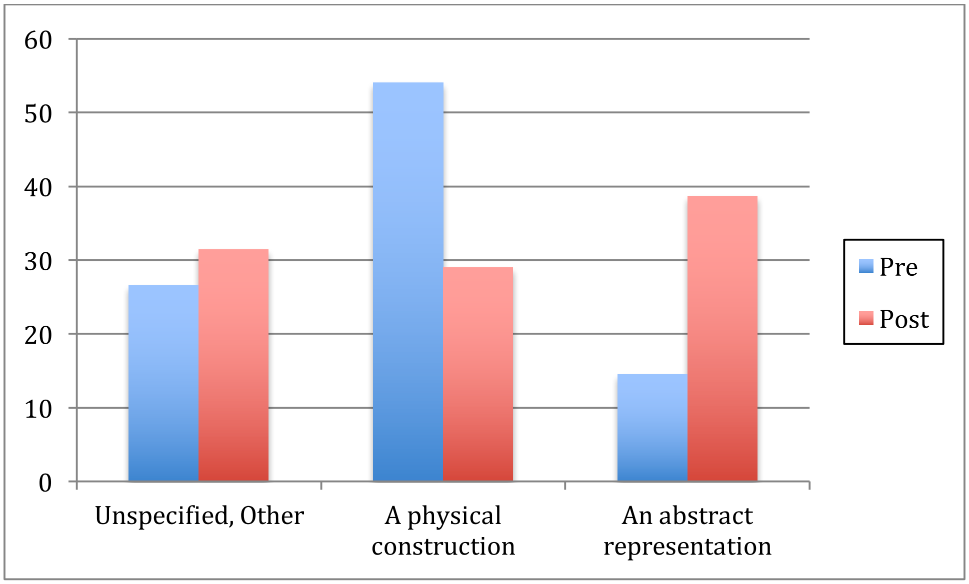


Figure 5. Shifts in the types of models teachers described in their generated examples of the practice

This new understanding of the purpose of modeling was also reflected in teachers' responses to the most important things they learned from the PD. For example, one teacher describes the new purpose for modeling 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 are promising, suggesting that teachers' views about modeling broadened during the PD, and teachers were more likely to see good modeling activities in ways that align with the new standards.

Impact of the Professional Development on Elementary, Middle, and High School Teachers

The model of professional development was implemented with mixed grade band groups. Each Science Area Partnerships created two groups so that the groups were matched on the numbers of elementary, middle school, and high school teachers. We examined whether the shifts described so far in this paper were exhibited differently in the three grade bands of teachers. It is usually assumed that the professional learning needs of elementary teachers and high school teachers may differ, given the different certification requirements and backgrounds for these teachers. The support for preparation of 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 took 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.

Table 8 presents differences in the impact between grade level. Interestingly there are no significant differences in 3D science learning, suggesting that the PD was effective for all three grade bands of teachers. We only find evidence of differences for only two measures - teachers' beliefs about students engaging with evidence in the classroom and teachers' beliefs about using student ideas in instruction. Looking at the mean differences by grade level (Table 9), we see that the biggest difference in beliefs about students engaging with evidence in the classroom are found at the high school level, while the smallest difference is found at the elementary level. Surprisingly, we see a positive change in high school teachers' beliefs about using student ideas in instruction, while the other two grade levels are not statistically significant from zero. Post hoc tests in both cases find statistically significant differences between high school and elementary, but not for differences between any other pairs.

Table 8. Grade-Level Effect Results for ANCOVA of Post-Test Scores on Pre-Test Scores

	N	**df**	**F-value**	**p-value**
3D Science Learning	177	2	2.04	0.134
Reform-Oriented Instructional Goals	168	2	0.89	0.412
Preparedness to Incorporate Science and Engineering Practices	169	2	1.81	0.167
General Instructional Preparedness	169	2	1.37	0.256
Beliefs about Traditional Instruction	169	2	1.02	0.362
Beliefs about Students Engaging with Evidence	169	2	5.16	0.007
Beliefs about Using Student Ideas in Instruction	168	2	4.17	0.017

Table 9. Pre-Post Differences 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

Summary and Conclusions

This is an exciting time for science educators. As a field, we have advanced in our understanding of what works in science classrooms, and what could work more effectively if it were more widespread. We have learned much from the successes and challenges of the last several decades of standards-based reform. This has led to the Framework, reflected in NGSS and in other standards reform efforts. The changes in the Framework are far reaching, and it is clear that teachers are a key part of bring these reforms to life in classrooms (National Research Council, 2015). Supporting teachers' professional learning will be essential. Research on changes in teacher practice has revealed the multiple aspects of teacher knowledge and beliefs involved in attempts to change practice (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 have described a program of professional development that explores how to help teachers begin to take the core shifts of the Framework and NGSS back into their own classrooms. The theory of action explored in this program assumes that teachers need to both understand the core shifts in the reform through examples of practice, and then work on how to apply them to their own practice. The approach to helping teachers work through the implications of the reform requires engaging with multiple perspectives -- experiencing 3D learning of science themselves, examining student thinking and practices engaged in the same kind of science knowledge building, and examining how teachers support students in those practices. Teachers are supported in moving fluidly between these perspectives, and then in taking what they have figured out about what a 3D science learning classroom should look like and planning how to take these changes back into their own classrooms.

We investigated these approaches in a two-pronged program through a state MSP initiative that focused on developing knowledge-building capacity in teacher leaders, and then involving those teacher leaders as facilitators of study group across the state. To examine the impact of this PD approach, we began by investigating how teachers' attempt to experiences the 3D learning themselves produced changes in their ability to apply the science practices to the disciplinary core ideas they studied (nature of matter). We found that within the domain the studied, teachers became more proficient in using the disciplinary ideas to explain phenomena. We then looked at affective outcomes of the PD, finding that teachers' confidence and feelings of readiness to take on the challenges of the reform increased through the PD. We view these data 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 experience and their reaction to the inevitable challenges that will arise.

The next step is to look at the teachers' perspective on particular issues involved in how to engage learners in their classrooms. This goes beyond positive or negative attitudes and starts to get at particular ideas about how to structure the 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.

Among the results, perhaps the most encouraging is the increase in sophistication of reasoning about pedagogical situations found in the questions about modeling scenarios. Supporting learners in the discourse-rich science and engineering practices cannot occur by following routines. Teachers will need a rich model of the goals, interactions, and epistemological understandings that translate knowledge building in science into grade-appropriate classroom interactions. Teachers will need facility in taking descriptions of science learning goals and mapping them into classroom tasks and appropriate criteria for student work. In this area, we found teachers reasoning about modeling with increasing sophistication as a result of the PD. Teachers showed better understanding and facility in generating situations in which models are being developed as tools for students to construct, compare, and evaluate explanations. They shifted from a view of models largely as physical models or models of structure, to a focus more on modeling process and mechanism. Importantly, the vast majority of scenarios teachers generated were outside the context of models of matter, demonstrating teachers' ability to take the ideas they had worked with and extend them to their own classroom settings.

This study presents some initial evidence illustrating the promise of practice-focused PD in peer-led study groups. It will be important to examine the study group interactions themselves, and explore the particular learning interactions that are most profitable in helping teachers grapple with the complex questions of practice. It will also be important to examine the strategies of the facilitators in leading these study groups and explore what strategies are most effective and how to support these strategies. Finally, documenting increased expertise in the teachers themselves is only the first step; future research will need to explore whether and how this increased expertise leads to changes in classroom interactions, and ultimately in student learning.

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Appendix A – Items used in Composite Scores and Items Qualitatively Coded

Science Content Composite Items

Explain as best you can in the space below, in nontechnical, 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 1 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 1 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 1 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 1 Response]

Which statement below best explains your answer? [Select 1 Response]

Instructional Goals Composite Items

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

Response Scale (4 options): None – Minimal Emphasis – Moderate Emphasis – Heavy Emphasis

Understanding science concepts

Learning science process skills (for example: 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 (4 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 (4 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 (6 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 (6 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 (6 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.

Qualitatively Coded Items

Modeling

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 NGSX, or have watched video about in NGSX. 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.

In this example activity, what is the model that students are developing?

What do you see as the purpose of having students develop and use models in this example?

Most Important Learning
What are the one or two most important things you feel you learned in NGSX?

Appendix B

Score	**Scoring Rules**	**Sample Responses**
Low (0)	Uses the ideas of "suction", "sucking", "pulling", or any other term that might symbolize a similar motion	*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 "suction" or "pushing", or is thoroughly neutral between them	*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)	Uses the idea of "pushing", "blowing", or any other idea that symbolizes a similar motion	*The space inside the vacuum (the 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.*