What Professional Development Strategies Are Needed for Successful Implementation of the Next Generation Science Standards?

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Introduction: The Central Role for Professional Development in Implementing NGSS

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; NGSS Lead States, 2013) requires a dramatic departure from approaches to teaching and learning science occurring today in most science classrooms K-12 (Banilower et al., 2013). This approach to teaching and learning builds on decades of research identifying problems with science classroom learning and promising strategies for what is needed to make learning more meaningful and effective for students (National Research Council, 2007). Central to the vision of teaching and learning articulated in the Framework and NGSS are three interrelated goals that affect how teachers need to support student learning:

1. *Core Ideas:* The Framework and NGSS shift the emphasis away from the breadth of too much content to a *focus on the in-depth development of core explanatory ideas*.
2. *Practices:* The Framework and NGSS outline *a central role for science and engineering practices* in which students develop key explanatory ideas and models through investigation and apply them to make sense of phenomena.
3. *Coherence:* Building explanatory ideas requires *treating science learning as a coherent progression* in which learners build ideas across time and between science disciplines.

The shifts in teaching practice required to achieve these goals are generally recognized to be substantial (National Research Council, 2012; Wilson, 2013). Tools including new curriculum materials and new assessments will be important supports to help the K-12 system move in these directions, but without a strong focus on aligned professional development, adopting NGSS and providing these resources will not be sufficient. Supporting students in the type of coherent sensemaking science practices called for the in Framework and NGSS requires a change in teachers' daily practices. These shifts in practice cannot be accomplished by learning *about* NGSS, or by developing a collection of isolated techniques. Instead it requires fundamental attention to what we now know about how to support teachers changing their practice.

To identify a professional development agenda, we begin in Section 2 with an analysis of how the Framework and NGSS demand real change in K-12 classrooms, exploring the three issues of core ideas, practices and coherence. We identify the central shifts in teaching practices on which professional development must focus if NGSS is to be successful. Then in Section 3, we review the implications of research on professional development, particularly in systemic attempts to change teaching practice, for teaching learning and teacher change of this sort, and consider how an effective PD system could support teaching change aligned with the Framework and NGSS.

What Demands on Teacher Learning Do the Framework and NGSS Create?

There are three areas of contrast between much current practice and the approaches to teaching and learning articulated in the framework and NGSS. These concern the kind of ideas we target for K-12 education (explanatory core ideas), how they are built (practices), and how they need to fit together (coherence). Each of these has implications for important shifts in teacher knowledge and practices. For each of these three contrasts, we consider how the Framework and NGSS build on prior reforms and extend them in substantial ways. Then we consider the shifts that are needed in teaching practices to support these changes, and the changes in beliefs, attitudes, and understanding that underlie these practices.

A Focus on Disciplinary Core Ideas

Teaching shift: The goal of instruction needs to shift from facts to explaining phenomena. This refocusing of goals for learning has real implications for what teachers need to do in helping students develop ideas. For example, consider a topic present in all middle school and high school science textbooks – cells. In middle school, students typically learn that all living things are composed of cells, and often learn the parts of the cell and the functions that each accomplishes. Yet these ideas, while important science in the right context, if learned as facts and definitions, are not linked to the important disciplinary ideas that help students explain the world. Knowing the names of the parts of cells and being told the function of each part does not help students build a coherent model that explains how cells get the materials they need to live. It does not explain the role that cells play in multicellular organisms, or why indeed, animals and plants need their cells to accomplish what the organism as a whole needs to survive.

While there is no disagreement between prior standards and NGSS that cells are a key part of learning biology, there is a real difference in how cells, like other ideas, are treated. The discipline of life sciences has identified cell structure and function as an important idea, so this is part of traditional curricula and the 1990s standards. Yet too often, students don't know why they are learning about cells, other than that "it's part of learning science" (Kesidou & Roseman, 2002). Students are not using the ideas to explain – to make sense of phenomena. Instead students are provided the idea of cells, are given the parts, are told their functions, and need to learn these ideas.

Contrast this with the approach outlined in the Framework and implemented in NGSS. The goal is to figure out how the structures of living things enable them to accomplish what they need to live (sub-idea LS1.A within LS1). As part of this investigation, students could learn about the parts living things are made of, and ask how these cells contribute to what living things need to survive. In NGSS, students are expected to be able to provide evidence to support the claim that living things are made of cells (NGSS, MS-LS1-1) and argue from evidence how cells work within a system to enable the living organism to achieve its needs (NGSS, MS-LS1-3), e.g., develop an evidence-based argument for why animals need cells.

This requires teachers and textbooks not to simply present facts and definitions as ends in themselves, but rather to help students continually work toward explanatory models, developing these ideas from evidence (Lehrer & Schauble, 2006). This requires a shift from *learning about* scientific ideas such as cells to *figuring out* scientific ideas that explain how and why phenomena occur (Passmore & Svoboda, 2012), e.g., how cells help organisms survive. Teachers need to see targets of learning such as cells as explanations for phenomena, and need to enact lessons in which they help students develop, test, and refine these explanatory ideas. This focus on developing explanations poses challenges for teachers in how to motivate lessons through phenomena that need to be explained, how to help learners develop these explanations, and tie them to the phenomena and questions that motivated them.

The Central Role of Science Engineering Practices

All NGSS standards are defined using science and engineering practices. A second key difference of the Framework and NGSS from prior approaches to science teaching and learning is in the focus on *practices*. The science and engineering practices reflect this commitment to “figuring out,” and characterize how learners build knowledge by posing questions, designing investigations, building explanations and models of findings, and engaging in argumentation to conduct principled comparisons of competing ideas and reach consensus.

The Framework and NGSS build on the efforts of the reforms of the last several decades that have attempted to make inquiry a more central part of how students learn science (Deboer, 2006). Indeed, the 1990s National Science Education Standards (NSES) emphasized inquiry as central to how students should learn science (National Research Council, 1996) and the AAAS Benchmarks included standards on habits of mind that specified ways of thinking scientifically (AAAS, 1993). However in both of these systems of standards, inquiry standards were separate from content standards. As the NSES and Benchmarks were implemented in various state standards, the content standards were the primary focus for curriculum frameworks, instructional materials, and assessments (*refs*). Indeed, the emphasis on inquiry was often understood to correspond to the idea of observing science ideas in action, equated with the idea of "hands-on science," but the sensemaking aspects of developing explanations were rarely emphasized (Spillane & Callahan, 2000).

The characterization of science and engineering practices builds on these earlier notions of inquiry to characterize a coherent system of activity, undergirded by common goals, expectations, and norms that govern how to do the work and define how progress in the discipline is made (Ford & Forman, 2006; Lehrer & Schauble, 2006; National Research Council, 2007, 2012). The science and engineering practices incorporate much of what has been thought of as inquiry, but elaborate how to engage in the work of inquiry, and how this work is part of building knowledge. The eight science and engineering practices in the framework and NGSS emphasize aspects often missing from these earlier interpretations of inquiry in classrooms. First, it emphasizes the knowledge building aspects of the science endeavor. Science is more than testing particular hypotheses to support or disconfirm them. The goal of science is using the evidence of these empirical tests to tease apart and refine explanatory accounts, and push toward generalizability of the ideas. The vision of science as practice emphasizes a connected system of practice that incrementally develops and refines knowledge as explanatory models (Lehrer & Schauble, 2006). Emphasizing the development of models focuses students on the coherence of the activity, moving from questions to empirical tests to explanatory models (Passmore & Svoboda, 2012; Stewart, Cartier, & Passmore, 2005; Windschitl, Thompson, & Braaten, 2008). The Framework and NGSS practices explicitly include elements of constructing explanations and developing general models that can be applied to a range of phenomena to explain how and why they occur.

A second clarification in the move from the narrower common conception of inquiry is the importance of social interaction and discourse in developing these explanatory ideas (Berland & Hammer, 2012; Duschl, 2008; National Research Council, 2007; Windschitl et al., 2008). The Framework and NGSS practices recognize that the process of developing explanatory accounts often requires principled ways to evaluate the success of an explanatory idea, and requires ways to adjudicate competing ideas. Hence the practice of argumentation from evidence is a key element in developing explanations and models. The articulation of the practices in the Framework and NGSS explicitly acknowledge that there are disciplinary approaches to argumentation that guide the knowledge building process in principled ways. The practices make explicit that the work of building, testing and refining knowledge is realized through scientific discourse and work with scientific representations and tools. Thus, the idea of engaging in discourse and working with others to reach consensus is an explicit element of the practices.

These two ideas are captured in Figure 1. The figure shows the knowledge building aspects of the practices on the right (developing explanations and solutions, leading to theories and models) and the way these knowledge products are derived from and guide investigation of the "real world" (the natural and designed world), on the left of the figure. The aspects typically captured by the narrower conception of inquiry realized in classrooms, primarily developing and testing hypotheses against data, are marked "Inquiry" in the figure. The use of empirical results not only to confirm hypotheses, but to develop explanatory accounts is indicated by the “Emphasis on Knowledge Building” as part of the development of theories and models. The role of social interaction and discourse is indicated in the argumentation practices that mediate between the knowledge and the real world.

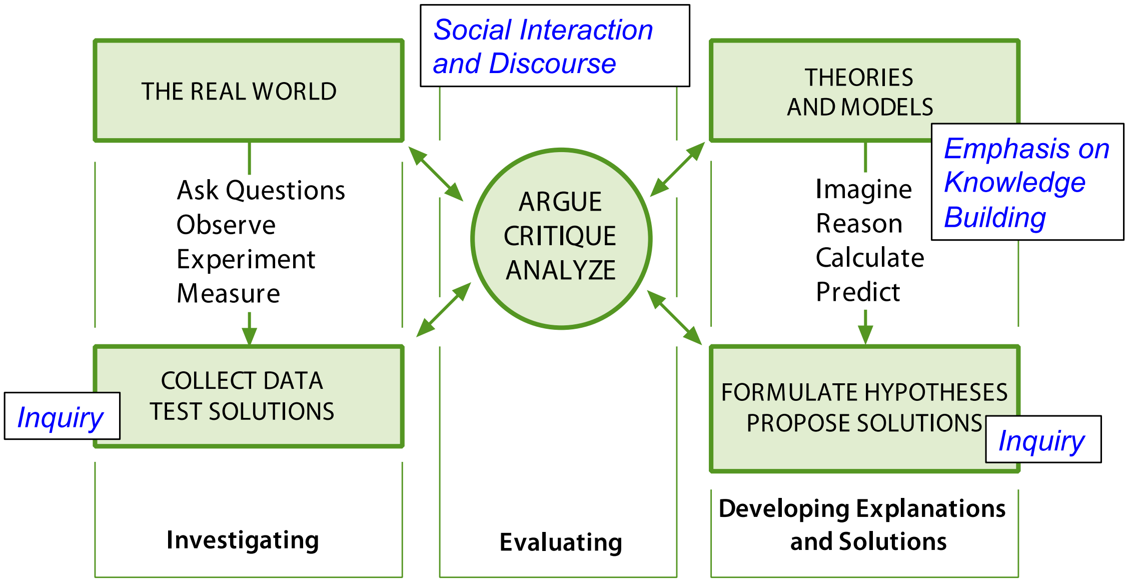


Figure 1. The shift from inquiry to science and engineering practices.
Adapted from* A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*, by the National Research Council, 2012, Figure 3-1, Washington, DC: National Academies Press.

The central role of practices in the Framework and NGSS is immediately apparent in the way standards are articulated. Rather than separate learning goals, the practices are used as a component of each and every standard in NGSS. The specific targets of science learning are not defined, as they have been for two decades, as the combination of a set of science ideas, and a set of inquiry skills. Such definitions leave open a focus on a plethora of disconnected facts, rather than a central set of explanatory ideas people can apply to make sense of the world. In NGSS, each science target is defined as a *performance expectation* that reflects a science or engineering practice developing or using science ideas (disciplinary core idea and crosscutting concept). Rather than simply knowing the fact that all living things are made of cells, a performance expectation in NGSS states that students should be able to “conduct an investigation to provide evidence that living things are made of cells” (NGSS, MS-LS1-1) and should be able to “develop and use a model to describe the function of a cell as a whole and ways parts of cells contribute to that function” (NGSS, MS-LS1-2). Developing and using a model pushes for more than knowledge of what the cell parts are called or what functions are associated with each part; it requires that students be able to construct a causal account that specifies how each part fits processes that obtain and transform resources from the cell's environment to enable the cell to function. Thus, the names of parts of the cell or identifying functions by name are no longer acceptable learning goals in and of themselves, unless these are part of developing and using ideas to argue from evidence or to develop and use a model to explain phenomena.

Teaching shift: Inquiry is not a separate activity—all science learning should involve engaging in practices to build and use knowledge. The teaching shift needed to teach with science practices aligns with the goals of developing explanatory knowledge. From a learning perspective, the way to develop robust flexible knowledge is to build that knowledge as part of applying it to solve problems and questions about the world (Edelson, 2001; Edelson & Reiser, 2006). If we want students to be able to use explanatory ideas about how living systems work to understand the world around them and to make decisions about nutrition, health, and medical policies, learning information by being told is an ineffective strategy (National Research Council, 2007, 2012).

Yet most science classrooms do not engage learners in investigating and explaining (Banilower et al., 2013; Schmidt et al., 2001; Weiss, Pasley, Smith, Banilower, & Heck, 2003). Many classrooms involve textbooks and teaching that present students with the ideas and use observations, experiments, and simulations so that students can observe what they have already been taught. The idea of helping students develop explanatory ideas through investigating phenomena, and incrementally build and refine ideas across time is a major shift for many teachers of science (Windschitl et al., 2008). Many teachers need to develop pedagogical approaches to support students in science practices such as argumentation and developing explanatory models (Jimenenez-Aleixandre, Rodriguez, & Duschl, 2000; Windschitl et al., 2008). Teachers also need support learning to orchestrate the classroom discussions that enact these practices (Alozie, Moje, & Krajcik, 2010; Michaels, O'Connor, & Resnick, 2008).

One challenging aspects of supporting practices is understanding how the practices work together. Although NGSS is developed using eight practices, these are identified to specify the different types of activity that need to work together to build, test, and refine knowledge. In fact, these eight practices constitute a single system of sensemaking. The practices need to work together to be coherent. While instructional situations may foreground one part of the process, or emphasize students' role in that part of the process, these practices draw their meaning from working together. For example, if students are going to argue from evidence, there needs to be a question they are trying to resolve through that argument. Thus at some point the students must have either developed or bought into a question for investigation. Evidence needs to arise from investigation.

Thus, although NGSS is represented as a collection of performance expectations, it is not productive to view these as isolated or modular learning goals. Teachers need to shift their mindset toward viewing instruction as building a coherent storyline, in which questions are grounded on phenomena, leading to investigations, and students develop models through argumentation, and refine those models through new phenomena that challenge existing models. The shift here is from a disciplinary organization, in which the discipline provides the breakdown an ordering of ideas, to organizing around the sensemaking activity. This shift poses challenges for teachers that are farther reaching than what is apparent on first perusal of the standards. Yes teachers need to learn to support students in argumentation, if they are not currently involved in supporting students in these practices. But doing so requires more than learning particular techniques to support this single practice of helping students learn to support claims with evidence. In meaningful scientific argumentation, the claims are steps toward developing explanatory models, and are constructed by interpreting evidence from investigations. Thus, organizing teaching around practices has implications not only for the specific activities students will be doing, but for the basic rules about how we motivate lessons and how lessons need to fit together. This represents not only learning new instructional moves, but represents for many teachers a shift in how they approach what it means for students to learn science, what counts as developing an answer to a science question, and for the types of assessments that are meaningful indicators of this learning.

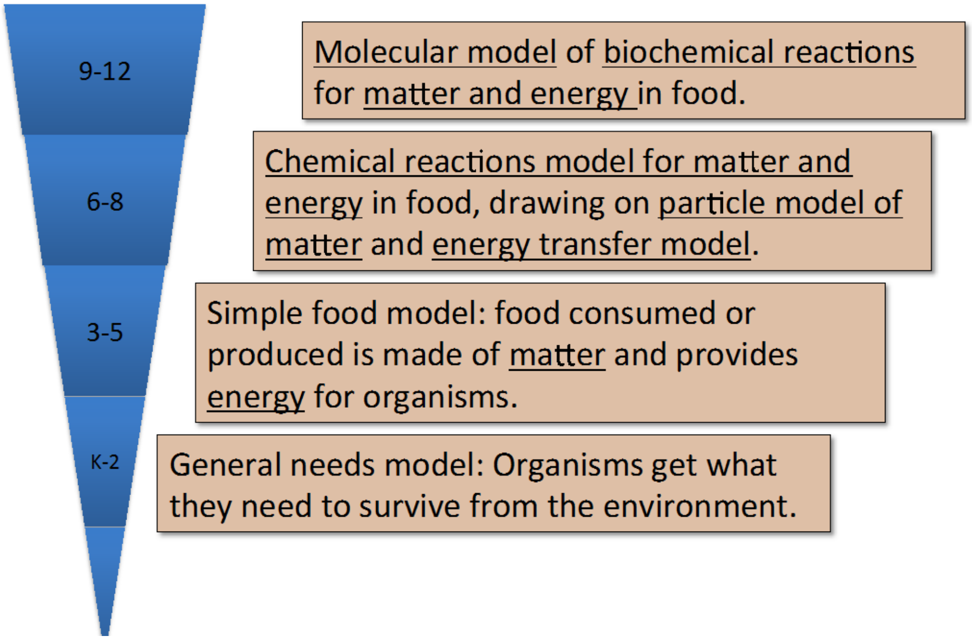
Coherence in Building Ideas Across Time

The argument for coherence draws on converging strands of research. First there is the recognition that a contrast between U.S. curriculum, standards, and classroom practices and those of other countries more successful in science reveal that our classrooms treat too many topics, too superficially, and in too disconnected a matter (Schmidt et al., 2001; Schmidt et al., 1996; Schmidt, Raizen, Britton, Bianchi, & Wolfe, 1997). Consistent with this comparison, there are clear arguments from learning research that developing and revisiting idea in greater depth across time is a more effective learning strategy (Corcoran, Mosher, & Rogat, 2009; National Research Council, 2007)

NGSS articulates how ideas should build across time and between science disciplines. There are several related aspects of coherence emphasized in the Framework and NGSS. The commitment in the Framework and NGSS is to articulating how ideas should build on earlier ideas. Within discipline, this means articulating the disciplinary core ideas as progressions, in which more sophisticated versions of the central science ideas are built iteratively across time. Indeed, each disciplinary core idea is represented in increasing sophistication across multiple grade bands. There is a K-2 version of the explanation, a 3-5 version, 6-8 and 9-12 answer to the same question. Each version goes deeper, drawing on what has been figured out in that discipline (e.g., life science, physical science, earth and space science) in prior grade bands. However each grade band results in a coherent explanatory model that is a satisfying answer to part of the question. Figure 2 shows an example of how the explanation for one of the life sciences ideas (LS1.C), *How do organisms obtain and use the matter and energy they need to live and grow?*, is built across time. The figure summarizes the explanation built at each grade level. In each grade band, students develop a coherent explanation, supported by evidence, convincing as far as it goes, but with some aspects unexplained or black-boxed that can be opened up in the next grade band.

These explanatory models also need to build on ideas across the science disciplines. Thus, for this biology idea, explanations at each level rely on what students have figured out about the nature of matter (how it cannot be created or destroyed) and how energy can be converted and transferred in a system, disciplinary core ideas from the physical science strand. Indeed, the phenomenon to be explained in middle school is only problematic, requiring an explanation, because ideas about energy and matter are brought in from physical science. It is because students have figured out that energy cannot be created or destroyed, in combination with the earlier idea that food provides us with energy, that creates the mystery to be explained—what happens in the body that allows us to "get energy" out of the food? Given what students have learned about transfer and transformation of energy, there must be some process that transforms the energy and transfers it to the system that can use it. Thus, the need for the explanation arises from this knowledge from the physical science strand. Without those understandings, there is nothing puzzling about how we get energy from food. The explanation to be constructed, then relies on knowledge about chemical reactions and their role in rearranging matter and enabling energy conversion to achieve a critical step in the argument for this biology question.

LS1.C How do organisms obtain and use the matter and energy they need to live and grow?



Molecular model of biochemical reactions for matter and energy in food.

Chemical reactions model for matter and energy in food, drawing on particle model of matter and energy transfer model.

Simple food model: food consumed or produced is made of matter and provides energy for organisms.

General needs model: Organisms get what they need to survive from the environment.

Figure 2. Building ideas across time, and between science disciplines for the life sciences idea LS1.C. (Connections to physical science ideas are underlined.)

Teaching Shift: Teaching involves building a coherent storyline across time. Treating learning as building coherent explanations, combined with the commitment to building knowledge through science practices, has important implications for how teachers need to approach science teaching. The teaching needs to be oriented toward helping student develop these coherent explanations. This means that explanations need to be grounded on phenomena that raise questions, and need to be justified based on argument that ties in what students have figured out so far and is supported by the evidence they have collected. In the traditional approach, when presenting a coherent explanation, teachers may focus on helping student understand how the pieces fit together. While this is likely a productive step, helping students construct such an explanation needs to go further. It requires introducing phenomena that can raise questions, uncovering problems with existing explanations students may have, and helping tease apart competing explanations through argument.

Traditional curriculum materials are typically organized according to the logic of the discipline. Teachers may introduce the next topic to be addressed by referencing its role in a larger set of issues. For example, most middle school textbooks introduce the study of body systems by introducing the goal of understanding how the human body functions, explaining that it is organized in systems (circulatory, respiratory, etc.) then introduce each body system as the next to be addressed, addressing multiple levels of organization (organs, tissues, cells) within each system. In contrast, to fully involve students in science practice, the class needs to be attempting to explain some phenomenon that requires using the idea to explain it. One such phenomenon is the various kinds of work that the human body can do, both internal (heart beating, breathing), and external (kicking, moving, pushing objects). The phenomena, combined with what students already know about how actions like this require energy, motivates questions about how that occurs. Students have already developed the idea that food can provide materials and energy for living things, but now are pushed to consider how this can happen. This may lead to recognizing or discovering empirically other relevant phenomena, e.g., that when we engage in vigorous exercise, we breathe much faster and our heart rate increases. Students also know that if they haven’t eaten for some time, they may feel tired and sluggish. Why do these phenomena occur? What is going on inside the body that leads to these effects? As students work on investigations and construct explanations, new questions arise and motivate the next lesson, rather than the disciplinary structure which says to learn about body systems one should learn systems x, y, and z.

This focus on explanations poses new challenges for teachers in how to motivate lessons. Although the teacher and the curriculum know that the goal is to address the important human body systems, if the class is engaged in science practices, there needs to be a reason to look at the next system, or the next level within the body system. The answer to why we are studying heart cells today should no longer be “because that’s part of the body system which is next in our list of chapters” but needs to be part of figuring out, based on evidence, how some phenomenon works. In many classrooms, although students may be told where the lesson is going, e.g., “our goal is to understand how heart cells are different from bone cells,” that is quite different from understanding how what is being investigated helps address a question that students have developed and have bought into (Edelson, 2001; Kanter, 2010). Learners should see the significance of ideas as they build and apply them, for making sense of the world, rather than being promised “you’ll need this next year.” Indeed, motivating the next topic and tying back to overarching questions is challenging for many teachers even when they explicitly take on this goal as part of their teaching (Rivet & Krajcik, 2008; Schneider, Krajcik, & Blumenfeld, 2005).

Summary of Shifts in Teacher Knowledge and Practice

Taken together, the shifts motivated by the Framework and NGSS are substantial. They reflect a systematic shift in how teachers need to think about how to motivate lessons and support students’ sensemaking in investigations. Yet we know that these approaches are feasible for teachers to develop, and are productive for student learning when they do so (National Research Council, 2007).

Several themes have emerged from this analysis that may pose challenges for many teachers:

- Lessons should be structured so that the work is driven by questions arising from phenomena, rather than topics sequentially pursued according to the traditional breakdown of lessons.
- The goal of investigations is to guide construction of explanatory models rather than simply testing hypotheses.
- Answers to science investigations are more than whether and how two variables are related, but need to help construct an explanatory account.
- Students should see what they are working on as answering explanatory questions rather than learning the next assigned topic.
- A large part of the teachers’ role is to support the knowledge building aspects of practices, not just the procedural skills in doing experiments.
- Extensive class focus needs to be devoted to argumentation and reaching consensus about ideas, rather than having textbooks and teachers present ideas to students.
- Teachers need to build a classroom culture that can support these practices, where students are motivated to figure out rather than learning what they are told, where they expect some responsibility for this work of figuring out rather than waiting for answers, and where they expect to work with and learn with their peers.

It is clear from this analysis that curriculum materials and assessments that reflect NGSS-aligned approaches, by themselves will not be enough, unless teachers can support the students’ science practices as targeted in NGSS-aligned curriculum materials and assessments. Yet, piecemeal changes and learning new isolated techniques will not be enough. This new vision represents substantial changes in how teachers engage in the practices of science teaching. Many teachers will need extensive support, not just in learning about NGSS, but in learning, trying out, and getting feedback on what it means to teach with this vision.

In the next section we consider what prior studies of professional development reveal about how to support the change in beliefs and practices required by NGSS.

What Does Research on Professional Development Suggest for Supporting the Framework and NGSS?

What Makes Professional Development Effective

Professional development (PD) for science in the U.S. does not currently reflect a coherent approach. Indeed Wilson (2013) suggests that "the U.S. PD system is a carnival of options." Research on effective professional development faces many challenges, including the rarity of programs that devote sufficient duration, attention to problems of practice, active participation, and institutional support for implementing what is being learned (Wilson, 2013). In addition, given the systematic nature of interventions needed to support teacher change in practice with aligned elements of the system, such as curriculum materials, assessments, and institutional support (Bryk, Sebring, Allensworth, Luppescu, & Easton, 2010), controlled experiments are challenging and often problematic. Despite these challenges, studies of professional development programs reveal an emerging consensus about those features that are most promising for supporting teacher learning (Borko, 2004; Garet, Porter, Desimone, Birman, & Yoon, 2001; Putnam & Borko, 2000; Wilson, 2013). Studies of professional development have revealed four related characteristics that concern the nature of learning experiences and their focus on application to teachers' classroom practice.

Professional development should be embedded in subject matter. First, professional development needs to *be deeply connected to subject matter* (Garet et al., 2001). While the learning usually has a more general goal (e.g., learning to support science practices in classrooms), it needs to be embedded in activities focused on specific examples of subject matter, so that teachers can grapple with both the science itself and how students learn about that science. Teachers' knowledge of how to support student learning does draw on general ideas (e.g., the importance of building on students' prior conceptions), but it critically depends on understanding how those general ideas play out as connected to specific subject matter issues (e.g., the nature of matter) and the challenges students face in making sense of this subject matter (Putnam & Borko, 2000).

For example, professional development experiences that focus on generic teaching issues such as classroom management, collaborative learning, or lesson planning, without emphasizing direct links to the subject matter, were judged less effective by teachers (Garet et al., 2001). In contrast, PD judged more effective was explicitly connected to issues of subject matter, such as the learning challenges students face in math story problems or learning about force and motion. Applying these ideas to NGSS suggests that PD on science practices should not be generic PD about how to support argumentation, or how to help students develop science models. Instead, the application of these ideas need to be connected to particular subject matter contexts, such as helping teachers investigate how to help students develop explanatory accounts using the particle model of matter, or evidence based arguments about population biology phenomena.

Professional development needs to involve active learning. Second, professional development tasks need to *involve active sensemaking and problem solving* (Garet et al., 2001). Teachers, like all learners, must go beyond being presented with ideas and strategies; they need the opportunity to analyze cases and apply the strategies themselves. In professional development, this translates into opportunities to study examples of interaction that reflect a particular teaching and learning issue, such as student explanation or teachers' questioning of student thinking. Such examples are material for analysis and sensemaking, rather than "model examples" of routines to be followed.

An aspect of this is that successful professional development programs require sufficient investment of time to enable teachers to grapple with the new ideas, analyze examples of the ideas in action such as student work or records of classroom interactions, and make incremental progress in understanding. The Garet et al. study documents the important both of number of hours and duration of the PD. Repeated experiences are needed to enable teachers to apply the ideas to new contexts. Indeed successful demonstrations of PD typically evidence both extensive hours and spread across time, such as summer long intensive workshops with follow up sessions during the school year. A typical program might consist of 8-10 three hour sessions in the summer (Heller, Daehler, Wong, Shinohara, & Miratrix, 2012) or even more intensive interventions such as 60+ hours in the summer followed by 30 hours spread over the school year (Roth et al., 2011). One-shot short duration PD interventions are unlikely to be effective.

Professional development needs to be connected to teachers' own practice. Third, to enable this active sensemaking, the substance of the work needs to *be connected to issues of teachers' own practice* (Ball & Cohen, 1996; Borko, 2004; Garet et al., 2001). In contrast to the traditional one-shot workshop presenting and discussing educational issues, teachers need sufficient opportunities and support to apply the ideas to changes in their own practice (Darling-Hammond, 1995; Putnam & Borko, 2000). Teachers need to "learn in, from, and for practice" (Lampert, 2009). Interventions that focus primarily on deepening teachers' content knowledge are likely to be insufficient. While knowledge of the science discipline itself is essential and may pose challenges if teachers' own subject matter knowledge is problematic (Kanter & Konstantopoulos, 2010), learning the science itself is not sufficient for teachers being able to translate what they have learned into their own classrooms (Heller et al., 2012). This is particularly critical for reforms, such as NGSS, that change not only what is taught, but change how it needs to be taught, e.g., by emphasizing science and engineering practices.

A recent experimental study provided convincing demonstration of the importance of connecting to teachers' classroom practice (Heller et al., 2012). Heller et al. studied 700 teachers in six states, who were either engaged in one of three professional development programs, or were control teachers receiving no PD. All three PD programs focused on the same science content (electrical circuits) and provided strong support for teachers to engage with phenomena and develop conceptual understanding of the science ideas. Teachers worked in groups, engaged in investigation and examined evidence to make sense of the phenomena. However, in two of these PD programs, additional experiences involved connecting what teachers were learning to their own classroom practices, while in one PD program, they were only engaged in reflections on their own science learning during the PD. In the first program linked to practice, teachers analyzed written cases of teaching practice about this science content. In a second program, also linked to practice, teachers received support in analyzing examples of their own students' work while they taught a unit about this content. All three PD programs showed demonstrable effects on teacher and student performance on test items compared to the control teachers. However only the two programs linked to practice showed lasting effects on the more demanding measures of students' abilities to explain their answers. Heller et al. argued that the "findings suggest investing in professional development that integrates content learning with analysis of student learning and teaching rather than advanced content or teacher metacognition alone." Similarly, teachers who participated in PD that included intensive analysis of video cases along with a focus on the subject matter learned more and produced more learning gains for their students than teachers involved only in PD on the science content itself (Roth et al., 2011).

Another reason for the importance of linking to practice is that a common obstacle to reform is seeing new ideas through the lens of traditional practice and underestimating the shift needed in one's own practice (Spillane, Reiser, & Reimer, 2002). Thus, both the general ideas of a reform (such as learning about science practices) and specific knowledge about how to apply these to one's classroom are critical. To accomplish both the understanding of the reform and specific knowledge about how to apply it requires "sustained, job-embedded, collaborative teacher learning strategies" (Darling-Hammond & Richardson, 2009), in which teachers work together to analyze the reform ideas and investigate the implications for their own practice, and then plan, implement, and reflect on their incremental attempts to realize these ideas in their own classrooms.

Research on changes in practice emphasizes the importance of focusing on "high-leverage practices" as instrumental in initiating change in teacher pedagogy (Ball, Sleep, Boerst, & Bass, 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. In the Framework and NGSS, both modeling and evidence-based argument represent dramatic divergences from common science teaching practice, and thus are key in helping teachers make the shift to a pedagogy aligned with the *Framework* and NGSS.

Professional development needs to be part of a coherent system of support. Fourth, a key issue that emerges as critical to realizing changes in practice is *the need for alignment* of the professional development with complementary work of implementing the reform (Garet et al., 2001). Different aspects of coherence have been highlighted across studies of professional development –

coherence with the teachers' goals, alignment with changes in standards, alignment with assessments, and curriculum materials that reflect the reforms (Darling-Hammond, 1995; Wilson, 2013). To support teacher learning as part of implementing NGSS and the Framework, then, connecting to practice requires that teachers explore what a coherent system of student learning, classroom teaching, assessment, and curriculum materials needs to achieve, and work on changes across these corresponding parts of a system.

Although research has identified these factors they are not independent from one another. Linking ideas to practice and providing opportunities for active learning necessarily take more time. Providing extensive opportunities for teachers to connect ideas to their practice necessarily involves intensive analysis and active learning. And ideally districts that recognize the need to invest in providing this time, and the opportunity for teachers to incrementally bring these ideas into their classrooms are presumably more likely to provide a system of supports.

Research-Based Recommendations for Professional Development for NGSS

In this section, we combine the demands for teacher learning we have identified with what the literature has identified as promising characteristics of professional development, and identify three recommendations for PD systems for NGSS.

Recommendation 1: Structure teacher sensemaking around rich images of classroom enactment. Teachers need to analyze and deconstruct examples in order to figure out what can be applied to their own teaching context. They need to work with rich cases that reflect the complexity of the teacher learning interactions, and contain enough context to explore the rationale for interactions and track their changes over time (Borko, 2004). One fruitful way to engage teachers with records of practice is for teachers to analyze video cases of teaching interactions (Ball et al., 2009; Boerst, Sleep, Ball, & Bass, 2011; Sherin & Han, 2004; van Es & Sherin, 2007). Video cases enable teachers to analyze student thinking, and the work of other teachers to elicit student ideas and help students work with one another's ideas. Video cases also help the teacher analyze how target subject matter and student thinking with these ideas are realized in classroom discourse (Boerst et al., 2011; Borko, Jacobs, Eiteljorg, & Pittman, 2008). The rich cases also 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; Roth et al., 2011). There are two related tasks in working with video cases. Teachers need to learn to analyze student thinking and classroom situations using the ideas of the reform (van Es & Sherin, 2007). This type of analysis is needed to anchor pedagogical content knowledge embodying strategies for supporting students in particular situations.

For example, a system of video cases could enable teachers to follow a group of students through a series of episodes exhibiting the storyline of their investigation in a classroom that is aligned to the goals and vision of NGSS (Roth et al., 2011; Windschitl et al., 2012). For example a series of video cases connected to the human body example presented earlier could follow students from identifying important questions to investigate about matter and energy in the body, and show how they trace the matter and energy through various investigations to find out how and where in the body energy is released from food to be used for body functions. An important part of the video case would be how students incrementally build an explanation across several weeks, arguing from evidence, uncovering further questions to be investigated, until the class reaches consensus.

Such rich cases could provide the fodder for active sense-making across the full range of the reform context from managing student talk to structuring the material activity of the classroom to support students' engagement in practices of science and engineering. Further, these images and the tasks associated with them then seed deep discussions of how a teacher might foster similar engagement in his or her own classroom.

Recommendation 2: Structure teachers' work to be collaborative efforts to apply NGSS to their own classrooms. A clear implication of designing for active learning "in, from, and for practice" is the emphasis on constructing *collaborative* learning environments, in which teachers work together to understand, apply, and reflect on the reforms (Garet et al., 2001; Wilson, 2013). Such collaboration is a key element of the active sensemaking identified as needed to understand the reform (Putnam & Borko, 2000). The group context for this discussion around specific examples of practice can create opportunities for the analysis and argumentation 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, 2007).

In investigating cases of NGSS aligned teaching, teachers could work together to debate their interpretations, and reach consensus as they do the science, analyze student work, and analyze teaching interactions. Teachers need to analyze and make sense of the ideas about the science to develop their own models and explanations. Cases could be presented as data to make sense of, not as examples to follow strictly. Teachers could analyze student work and raw classroom video (without a narrative telling them a single "correct interpretation") to uncover challenges the ideas and practices pose, and how students' ideas differ from one another and change over time. These PD tasks, just as the nature of learning in NGSS, would focus on knowledge-in-use rather than on abstract decontextualized knowledge. Whether working on science, student learning, or teaching questions, teachers would be asked to connect what they are seeing to their own classroom experiences, e.g., contrasting the way they are learning about the human body in the PD sessions with typical approaches currently used to teach the human body in their school. They could work to adapt lessons they currently teach to incorporate science and engineering practices, and to restructure the lessons to focus on a coherent storyline, in which questions about phenomena motivate the need to develop and use explanatory models.

Recommendation 3: Capitalize on cyber-enabled environments. The importance of responding to teacher learning needs across the K-12 system, combined with the need to offer sustained, job-embedded professional development, raise the question of using technology as part of a solution in addressing problems of scale. There are a variety of ways to incorporate technology, including the materials teachers use (e.g., digital video of classrooms, video of presentations), and the medium for communication (e.g., online course tools). The research on cyber-enabled learning is still emerging. Dede, Ketelhut, Whitehouse, Breit, and McCloskey (2008) reviewed the state of research on cyber-enabled PD. Dede et al. call for investments in scholarship in online professional development to build a much need evidence-based conceptual framework that provides robust explanatory power for theory and model building. They are critical of a traditional emphasis on pure evaluation studies of "learning innovations" and recommend empirical studies with promise of *generating knowledge* on several critical variables, for example, design features, shifts in teaching practices, and technology-mediated interactions. Most importantly they call for studies that do not replicate traditional PD, but studies with methodologies and theoretical assumptions well suited to a cyber-enabled environment. Careful attention to the affordances of online tools can, in some cases, lead to teacher learning with positive outcomes equivalent to face-to-face professional development (Fishman et al., in press).

There are clearly potential benefits that appropriate use of technology could potentially provide. Expertise for teacher discussion groups could be provided through guiding videos. Technology can enable access to resources such as video cases, and examples of how curriculum materials can support students' science and engineering practices. Linked examples of curriculum materials, classroom enactments, and resulting student work can be provided.

However, a standard online course is unlikely to support the change in teacher practice that is needed. The challenge in adapting technology as part of a PD solution is to retain what we know is effective in PD – supporting a community of teachers working to make sense of reform ideas and apply them to their own classroom practice, supporting them in cycles of investigation, classroom teaching, and sharing and reflecting on the results from their own classrooms. Thus, online courses in which teachers are presented with information are unlikely to support change in teacher practice that is needed. Even the typical types of online discussion groups that accompany online courses could be insufficient. While these assigned discussions at least provide opportunities for teachers to dig deeper into the ideas and attempt to make sense of them with their peers, this doesn't provide the context in which teacher are working together to apply the ideas to their own practice. Technological supports, ideally, would be part of a system of supports for teachers engaged in the cycles of investigation of the science and pedagogy, enactment in their own classrooms, and study of their classrooms as they attempt to enact the ideas.

Conclusions

We are at an exciting time. Decades of research have led to recommendations for new science standards that capitalize on what is known to be effective about learning. The modern emphasis on accountability systems have led states to work together to develop and begin to adopt a more coherent system of standards. The Framework and NGSS have the potential to move our K-12 science system forward in important ways. We know that the type of ambitious teaching reflected in NGSS is possible, occurs in some modern classrooms, and leads to impressive engagement and learning for students. But there is much to be figured out to implement NGSS at scale.

The vision is ambitious. Indeed, although there is compelling research to motivate all the different parts of NGSS, we have not had the opportunity to empirically investigate the effects of a coherent system of science education, in which students were supported in science and engineering practices across 13 years, each year was carefully architected to build on prior years, and teachers and the community shared a common approach to what it means to learn and do science.

The vision has great promise, but also great demands. We know that with sufficient investment of time, resources, and aligning different parts of the system, teachers can learn more effective ways to practice the craft of teaching and support students in more ambitious science learning. There are certainly political and pragmatic challenges facing these efforts. But our community of science educators, researchers, and policy makers has a rare opportunity to make real progress on the shape of science teaching and learning in the United States.

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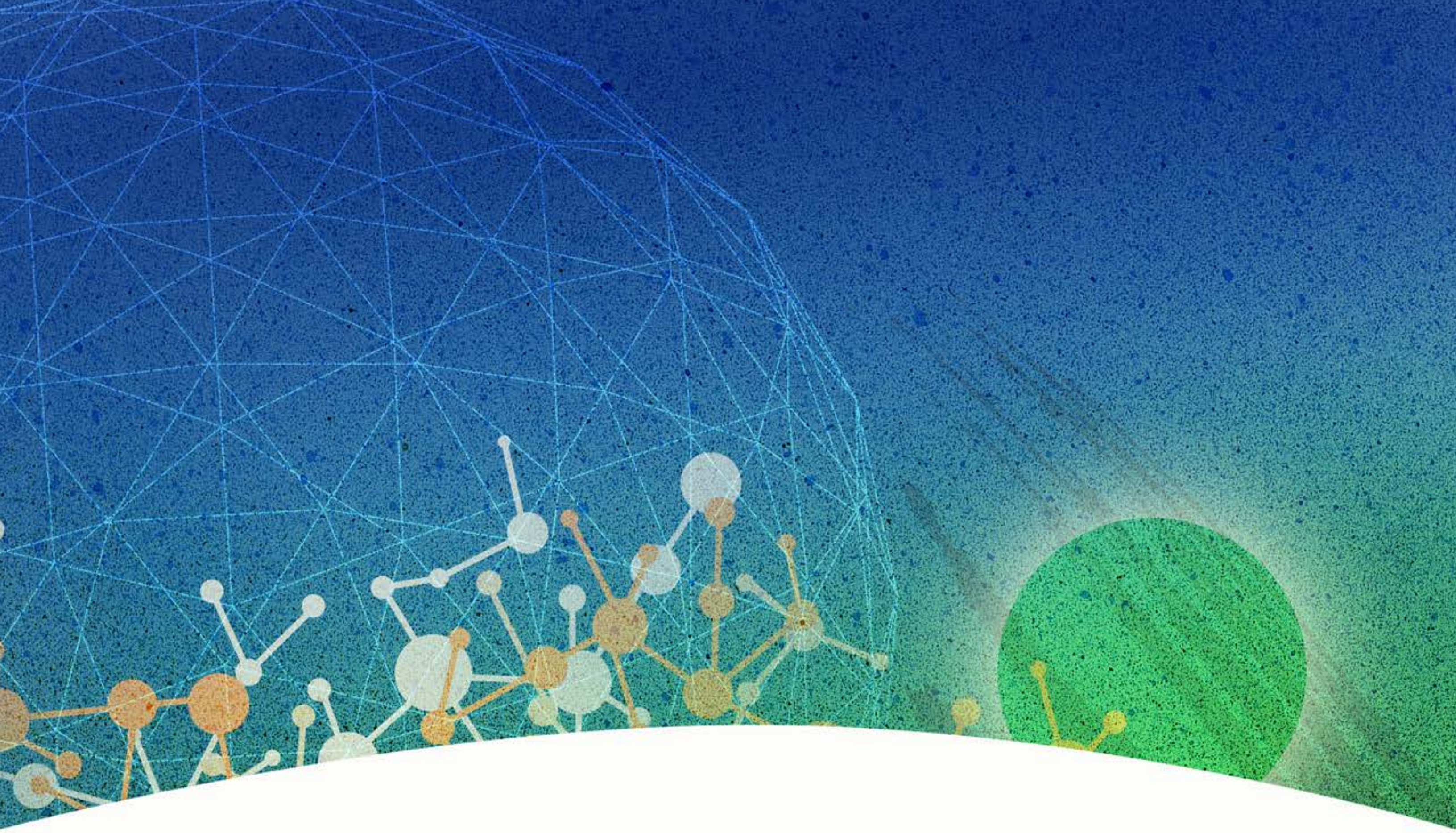

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