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Teacher and Student Supports for Implementation of the NGSS

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TEACHER AND STUDENT SUPPORTS FOR IMPLEMENTATION OF THE NGSS

by

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A thesis submitted to the

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This thesis entitled:
Teacher and Student Supports for Implementation of the NGSS
written by Samuel Severance
has been approved for the School of Education

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The final copy of this thesis has been examined by the signatories, and we find that both the content and the form meet acceptable presentation standards of scholarly work in the above mentioned discipline.

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ABSTRACT


Teacher and Student Supports for Implementation of the NGSS.

Thesis co-directed by Professor William Penuel and Professor Tamara Sumner.

Through three articles, this dissertation examines the use of supports for implementing the Next Generation Science Standards (NGSS) within a large urban school district. Article one, titled *Organizing for Teacher Agency in Curricular Co-design*, examines the need for coherent curriculum materials that teachers’ had a meaningful role in shaping and how the use of a co-design approach and specific tools and routines can help to address this need. Article two, titled *Relevant Learning and Student Agency within a Citizen Science Design Challenge*, examines the need for curriculum materials that provide students with learning experiences they find relevant and that expands their sense of agency and how a curriculum centered around a community-based citizen science design challenge can help achieve such an aim. Article three, titled *Implementation of a Novel Professional Development Program to Support Teachers’ Understanding of Modeling*, examines the need for professional development that builds teachers’ understanding of and skill in engaging their students in the practice of developing and using models and how a novel professional development program, the Next Generation Science Exemplar, can aid teachers in this regard by providing them with carefully sequenced professional development activities and specific modeling tools for use in the classroom.
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CHAPTER I

INTRODUCTION

by

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PROBLEM CONTEXT

This dissertation focuses on supports for implementation of the Next Generation Science Standards (NGSS; NGSS Lead States, 2013) within a large, urban school district. The NGSS puts forth a new vision for science education that calls for shifts in the way that students learn science. Achieving this vision of science education will prove challenging for education systems seeking to adopt the NGSS as these shifts represent a significant change from past ways of science instruction (Krajcik, Codere, Dahsah, Bayer, & Mun, 2014; Penuel & Fishman, 2012). Chief among these shifts is the notion of “three-dimensional science learning” (National Research Council, 2012), wherein students engage in the use of science and engineering practices to build pieces of disciplinary core ideas and crosscutting concepts over time. In addition, the NGSS, as carried forward from A Framework for K-12 Science Education...
(Framework, National Research Council, 2012), calls for an emphasis on fewer core ideas as well as for attending to issues of equity, that is, for using strategies that support all students in having more meaningful science learning. These demands, as well as others, in the NGSS and the Framework, serve as the context for this dissertation. This dissertation, across three articles, explores two overarching questions:

1. How do teachers and students take up supports for implementation in activity related to realizing the vision for science education established in the Framework and carried forward in the NGSS?

2. What design principles can be derived from efforts occurring across the implementation space of a single district that can support the effective design and implementation of innovations embodying the Framework and NGSS?

BACKGROUND

A New Vision for Science Education

In 2012, the National Research Council (NRC) released A Framework for K-12 Science Education: Practices, Cross-Cutting Concepts, and Core Ideas (National Research Council, 2012). In this comprehensive document, often simply called the Framework (NRC, 2012), a panel of experts developed a new, ambitious vision for science education at the primary and secondary level. This vision became the basis for the development of the Next Generation Science Standards (NGSS) released in April, 2013 (NGSS Lead States, 2013). Twenty-six states and several national groups took part in developing the NGSS and currently thirteen states and the District of Columbia have adopted some form of the NGSS to serve as their science standards. In states that have not officially adopted the NGSS, some individual districts have begun the process of adopting the standards on their own (Severance, Penuel, Leary, & Sumner,
SUPPORTS FOR IMPLEMENTATION OF NGSS

2016), such as the district that serves as the setting of the articles in this dissertation. For districts in both adopting and non-adopting states, meeting the demands of the Framework and the NGSS will prove no easy task as they call for significant shifts to how students learn and experience science in school (Krajcik et al., 2014; Penuel & Fishman, 2012).

**Shifts Called for in the Next Generation Science Standards**

Perhaps the most significant shift called for in the Framework and the NGSS centers on having students achieve “three-dimensional science learning” (National Research Council, 2012). Three-dimensional science learning calls for the integration of disciplinary core ideas, science and engineering practices, and crosscutting concepts into a cohesive and meaningful experience for students (National Research Council, 2012, 2014a). This form of learning foregrounds how scientific knowledge and the means by which we achieve such knowledge are inseparable from one another and that a unity to science exists across disciplinary subfields. Krajcik and colleagues (2014) provide a rationale for an integrated approach to science education:

> If we want students to learn the content, they have to engage in the practice. But if we want students to learn the science and engineering practice, then they have to engage in content. Leave one out, and students will not develop proficiency in the other (p.159).

In essence, three-dimensional science learning demands a qualitatively different experience for students that departs from previous incarnations of science education. In previous incarnations of science education students may have, for example, learned the disciplinary core ideas as “facts-in-isolation” and the practices as skill components within a linear scientific method (Bacolor, Peterman, Chowning, & Bell, 2015; Bell, Bricker, Tzou, Lee, & Horne, 2012; Eisenhart, Finkel,
SUPPORTS FOR IMPLEMENTATION OF NGSS

& Marion, 1996; National Research Council, 2012). The purposeful integration of science and engineering practices, disciplinary core ideas, and crosscutting concepts, demands students to more authentically engage in the sort of knowledge-building characteristic of real scientists and engineers and how they develop scientific and engineering knowledge in their activity (National Research Council, 2012).

A key mechanism of achieving three-dimensional science learning is engagement with science and engineering practices. The Framework describes science practices as those scientists employ as they investigate and build models and theories about the world, and engineering practices as those engineers use as they design and build systems (National Research Council, 2012). The use of science and engineering practices allows for the realization of three-dimensional science learning as all science learning should involve engaging in practices to build and use knowledge (Reiser, 2013). Specifically, students should engage in science and engineering practices to build pieces of disciplinary core ideas and connections to crosscutting concepts (Reiser, 2014). Demanding that students engage in science and engineering practices prevents teaching the practices as an isolated concept apart from content and provides students with the needed opportunity to actually experience the practices themselves in order to comprehend them (National Research Council, 2012). Additionally, students should develop the capacity over time to use the practices together or in isolation as needed, reflecting views that the science and engineering practices interrelate “as an unfolding and often overlapping sequence, or a cascade” (Bell et al., 2012, p. 18).

Besides the fundamental shift towards three-dimensional science learning characterized by the integration of science and engineering practices, the Framework also calls for other substantial shifts to science education to achieve more meaningful science learning (National
SUPPORTS FOR IMPLEMENTATION OF NGSS

Research Council, 2012). In a departure from seeking broad coverage of content, the Framework calls for a focus on a limited number of core ideas (National Research Council, 2012). In restricting the number of disciplinary core ideas to a select few, the Framework seeks to address the prevalence of sacrificing depth for breadth in American science curricula as compared to the science curricula from other countries (Schmidt, McKnight, & Raizen, 1997). In addition, focusing on core ideas in science addresses concerns about the lack of coherence in American science curricula (Schmidt, Wang, & McKnight, 2005).

Focusing on core ideas forces students to move from learning about “facts to explaining phenomena” (Reiser, 2013, p. 3) which builds coherence, another demand of the Framework. The Framework demands that curriculum provide students with a sense of coherence so that students build understanding over time (National Research Council, 2012). Such a stance supports an emphasis on developing students’ proficiency in science in a coherent way across grades along a learning progression (Duncan & Hmelo-Silver, 2009; National Research Council, 2012). In practice, curricular materials that demonstrate curricular coherence will provide students with an experience in which they can understand the object of their learning—why they are learning something—and make meaningful connections between ideas over time (Fortus, Sutherland Adams, Krajcik, & Reiser, 2015; Reiser, 2014; Schmidt et al., 2005). The structure of curricular materials that students will experience provides a means to achieve coherence and build understanding over time. To promote coherence, curricular materials should include sequences of activities where students utilize science and engineering practices to investigate a phenomenon of interest or devise a solution to a meaningful problem (Reiser, 2014).

In addition to focusing on a few disciplinary core ideas and promoting coherence, the Framework also explicitly identifies the importance of making learning relevant to all learners.
SUPPORTS FOR IMPLEMENTATION OF NGSS

(National Research Council, 2012). All too often learners experience an encapsulation of schooling, a situation where students engage in activities that lack authenticity and relevance to their lives outside of the classroom (Engeström, 1991). In addition, these activities often do not provide meaningful opportunities for students to exercise meaningful agency around an issue relevant to students (Eisenhart et al., 1996; Roth & Lee, 2004). Supports for implementing the vision of the Framework should seek to meaningfully integrate students’ interests and experiences from outside of school (National Research Council, 2012). In doing so, science learning becomes more personally relevant. In addition, purposefully seeking to incorporate students’ interests and experiences into their science learning attends to issues of access and indexes another key shift in the Framework around equity and seeking “science for all” students. Specifically, validating and making available the interests and experiences of all students in the science classroom promotes broader participation within the scientific enterprise, particularly from historically underrepresented groups (National Research Council, 2012).

**Challenge of Implementing the Next Generation Science Standards**

The degree to which education systems can bring the vision of the Framework and the NGSS into reality will determine the actual influence of these bold documents. Successful implementation of the shifts called for in the Framework and NGSS will likely require a coherent approach. Coherence, in this sense, refers to where all components of a complex education system “work together in a harmonious or logical way to support the new vision” (National Research Council, 2012, p. 245). In terms of framing a strategic approach to implementation, the Framework identifies key components of the implementation space within science education systems that must undergo shifts to effectively enact the vision embodied in

In terms of curriculum, the lack of available curricular materials poses a significant obstacle to effective NGSS implementation. Few curricular materials that embody the three-dimensional science learning called for in the Framework and NGSS exist (National Research Council, 2012; Roseman, Fortus, Krajcik, & Reiser, 2015). Having curriculum materials provides models for what standards-based teaching can look like (Krajcik, McNeill, & Reiser, 2008). They also provide supports to enable students to follow a learning progression (Smith, Wiser, Anderson, & Krajcik, 2006). Looking to past implementations of science standards, such as the National Science Education Standards (NRC, 1996), a lack of curriculum materials aligned to reforms may prove the norm, lessening the potential impact of new standards (Kesidou & Roseman, 2002). Curricular materials support teachers in reconstructing their teaching practice to align with particular visions for student learning (Remillard, 1999), consequentially, a lack of available resources aligned to the Framework and the NGSS would greatly challenge teachers to meet any new shifts. Additionally, students who experience a coherent curriculum have better learning outcomes (Fortus et al., 2015; Krajcik & Mamlok-Naaman, 2006; Krajcik et al., 2008; Shwartz, Fortus, Krajcik, & Reiser, 2008). A lack of curricular materials impacts the ability of teachers to support the underlying shift called for in the Framework related to coherence, notably, how a student perceives and finds meaning in an activity.

Teacher development also poses unique challenges to achieving effective implementation of the NGSS. Typically, few science teachers experience intensive science professional development and science professional development typically lacks subject specific support for
teachers (Banilower et al., 2013). Additionally, science professional development typically focuses only on developing isolated skills and techniques (Wilson, 2013). Given the numerous challenges teachers will face in implementing the shifts called for in the Framework, providing teachers with intensive, comprehensive support around NGSS implementation seems an essential requirement in addition to having appropriate curricular materials. In particular, teacher development efforts should focus on developing teachers’ understanding of three-dimensional science learning and its components (National Research Council, 2012). Enacting three-dimensional science learning will require new forms of pedagogical expertise and practices. Professional development efforts that focus on developing teachers’ pedagogical practices in order to effectively implement three-dimensional science learning could support broader implementation efforts, such as the development of teachers’ “curriculum knowledge” (Shulman, 1987, p. 8). As teachers engage with, ideally, curriculum materials aligned to the NGSS, they must have a firm understanding of the shifts called for in the Framework to draw on when planning, adapting materials, and eventually, realizing such shifts in instruction. For example, teachers will need to comprehend demands for curricular coherence and making learning relevant for students (National Research Council, 2012; Reiser, 2013, 2014)

Shifts in instruction, defined as the methods of teaching and the learning activities students engage in (National Research Council, 2012), also will prove challenging for teachers and students to meet. For example, teachers often adhere to a position that students should “learn about” (Reiser, 2014) a concept before engaging in activities that may have allowed them to “figure out” (Reiser, 2014) the concept (Banilower et al., 2013). Additionally, teachers do not emphasize the importance of science practices in their instruction (Banilower et al., 2013). While not endorsing a specific instructional approach, the Framework does suggest the need for
teachers to develop the capacity to use a variety of instructional approaches in order for their students to achieve scientific literacy (National Research Council, 2012). At minimum, teachers should integrate the various science and engineering practices into their instruction. In addition, teachers should seek to promote social, collective engagement with the practices, particularly those associated with scientific discourse (Reiser, 2013). Such efforts to reify three-dimensional science learning as instructional practices within the classroom will ideally occur in tandem with providing curriculum aligned to the NGSS and teacher professional development designed to support NGSS implementation.

**What We Learn about Learning from Studying Implementation**

Examining how districts, teachers, and students take up supports and use them to mediate their activity allows for insights into how people learn to productively achieve reforms through the use of collectively available tools. Taking a sociocultural frame, with an emphasis on tenets of Cultural-Historical Activity Theory (CHAT), the implementation supports under examination in this dissertation serve as tools that by and large came to participants—teachers and their students—from a designer. Such supports, as with all tools, contain some ambiguity in their meaning and purpose (Engeström, 2011). Following the idea of Vygotsky’s functional method of double stimulation (1978), the participants must “take up” the supports or tools and imbue them with meaning in order to make use of them (Engeström, 2001), thus actually completing their design. As the introduction of a tool “re-creates and reorganizes the whole structure of behavior just as a technical tool re-creates the whole structure of labor operations” (Vygotsky, 1981, p. 140), studying the implementation of supports can provide insights into how their use by participants can precipitate change (or not) that results in a transformation or shift to new activity, in this context, towards forms of activity that embody the ambitious vision for science
education put forth in the NGSS. As such, studying how participants go about achieving this vision provides opportunities to observe expansive forms of learning (Engeström & Sannino, 2010), notably within the context of external educational reforms, given that how to achieve implementation of the NGSS in teachers’ and students’ activity systems (e.g. professional development settings, schools, classrooms) remains ambiguous and will require developing new forms of activity.

**UNIFYING THEME**

Currently, districts seeking to adopt the NGSS and achieve the vision for science education called for in the Framework face a daunting challenge. Implementation of the NGSS requires *something* to implement, and few resources exist that meet the needs of districts, particularly in the areas of professional development and curricular materials (Krajcik et al., 2014; Roseman et al., 2015; Wilson, 2013). The large urban district that serves as the context for each of the three articles in this dissertation has chosen to move towards adopting the NGSS. A long-term research-practice partnership (RPP; Coburn, Penuel, & Geil, 2013), of which the district is a member, has sought to support the district in their aims of NGSS adoption. This assistance has focused on how to support the district in navigating various problems of practice relevant to the implementation of the NGSS. These problems include (Article 1) the need for coherent curriculum materials and empowering teachers to have meaningful influence in shaping such materials, (Article 2) the need for materials that expand student agency and provide learning experiences connected to the local community that students find relevant, and (Article 3) the need for professional development that builds teachers’ understanding of science and engineering practices and how to meaningfully engage their students in such practices.

**Unifying Theme in Relation to Articles**
Article 1: Organizing for teacher agency in curricular co-design. Teachers typically have little say in the design of curricular materials and often only have the opportunity to enact the designs of others (Ormel, Pareja Roblin, McKenney, Voogt, & Pieters, 2012). Such an arrangement not only deprives teachers of the chance for intense professional development, it deprives teachers of the opportunity to develop professional agency and to leverage their expertise to influence a significant aspect of their profession: curriculum. This first article primarily examines how the tools and processes of co-design—a process where teachers, researchers, and developers work together to design education innovations (Penuel, Roschelle, & Shechtman, 2007; Voogt et al., 2015)—can serve as a means for promoting agency and helping teachers learn about the NGSS. Nine teachers, five district administrators, two curriculum writers, and eight researchers took part in co-design activities to develop a new NGSS-aligned high school biology curriculum for use across the district. Employing a CHAT conceptual framework, this article examines the design of the design space itself and how specific tools and processes within the design space served to productively mediate participants learning and promote agency. These tools included (1) a Storyline tool (Reiser, 2014) designed to support development of coherent, three-dimensional curricular units, (2) small group structures organized to position teachers in lead design roles, and (3) internal review processes consisting of surveys and critique sessions where participants had the chance to openly critique created materials and the design process. In terms of learning goals, the RPP sought to build teacher expertise around several key shifts associated with the Framework, such as three-dimensional science learning and curricular coherence. This article describes how attending to issues of agency promoted teacher buy-in and ownership. Acknowledging teacher agency signals that implementation
provides a “learning opportunity,” one the collective participants in the co-design space figured out together.

**Article 2: Relevant learning and student agency within a citizen science design challenge.** Students typically experience an encapsulation of schooling with few opportunities to engage in meaningfully relevant activity or to meaningfully exercise agency (Engeström, 1991). Embedding citizen science into formal curricular materials provides a potential means to address issues of relevance and agency and support the vision for science education put forth in the Framework and NGSS. Using a sociocultural conceptual framework emphasizing CHAT, this second article examines the implementation of a curriculum designed to align to the Framework and NGSS and that employs a citizen science component. This article examines how the curriculum, which addresses the disciplinary core idea “Ecosystems: Interactions, Energy, and Dynamics” from the NGSS (NGSS Lead States, 2013), influenced students’ sense of agency and how they perceived the relevance of their learning towards themselves, their class, and their community during the implementation of the curriculum. Central to this curriculum’s design, students utilized science and engineering practices as mediating tools to resolve a citizen science design challenge. The challenge called for students to determine which tree they should plant in their local ecosystem and where in order to help maintain the biodiversity of their ecosystem and maximize the services their urban ecosystem provides. Students developed a solution to this challenge and saw their solution reified through local community partnerships, i.e., they planted the tree they determined best meets the challenge. This study involved twelve pilot teachers implementing the curriculum for approximately 975 students. Two teachers and six students were recruited to serve as focus subjects.
Article 3: Implementation of a novel professional development program to support teachers’ understanding of modeling. Modeling is a new practice unfamiliar to most teachers (Van Driel & Verloop, 1999, 2002). Although science teachers may have a general definition of a model, they have conceptions of modeling that differ from those used by scientists (Van Driel & Verloop, 1999). Innovative professional development designed to promote the development of teachers’ expertise in the practice of modeling offers a potential means to address this issue. This third article examines how and in what ways the Next Generation Science Exemplar (NGSX), a novel hybrid professional development program utilizing both in-person and online activities, supported (or not) a cohort of teachers in developing their capacity to productively engage students in the science and engineering practice of developing and using models as called for in the NGSS. Specifically, this article examines how did the activities and tools embedded within the NGSX program mediate the development of various teachers’ understandings of the practice of modeling and how did classroom adaptation and implementation of activities and tools from the NGSX program further mediate these understandings. Developed by researchers from several research institutions, the NGSX professional development program introduces teachers to instructional strategies supporting modeling. As part of the NGSX design, teachers enact these instructional strategies, such as tools designed to promote public reasoning, within their own classrooms with their students. A total of thirty participants took part in this study, including five district administrators, four researchers, and twenty-one practitioners who engaged in the NGSX professional development program. Analysis of data utilized a sociocultural conceptual framework with an emphasis on mediated action (Wertsch, 1994).

OVERALL RESEARCH QUESTIONS
SUPPORTS FOR IMPLEMENTATION OF NGSS

The three articles in this dissertation all share a focus on the implementation of materials specifically designed to help address problems of practice the partner district under study has faced in implementing the NGSS. Collectively, these studies will attempt to answer the following overarching questions:

1. How do teachers and students take up supports for implementation in activity related to realizing the vision for science education established in the Framework and carried forward in the NGSS?

2. What design principles can be derived from efforts occurring across the implementation space of a single district that can support the effective design and implementation of innovations embodying the Framework and NGSS?

CONTEXT FOR RESEARCH

The research for this dissertation took place within a single, large, urban district. Over the last several years, the district has had, on average, over 80,000 students, 70% of which received free or reduced lunch, a marker of poverty. Of these 80,000 students, 55% identified as Hispanic or Latino, 20% identified as white or Caucasian, 15% identified as Black or African American, and 5% identified as Asian or Pacific Islander. Schools within the district have varied as to their percentage of learners classified as English Language Learners (ELL): some schools have reported only 1% of their students as having ELL designations while other schools have reported as much as 90% of their population as having ELL designations. The district has had an active school board, which has overseen a veteran superintendent who in turn has managed a large district leadership structure. Within the district leadership, numerous offices specialize in certain aspects of the district’s operations including assessment, teacher development, and curriculum. The individuals from the district most involved in the work of the RPP during the course of this
research came from the district curriculum office. The district curriculum office typically makes recommendations on curricula, including textbooks such as the current biology textbook, *BSCS: A Human Approach*. In addition, the curriculum office sets instructional pacing guides for the district, essentially, a calendar that provides recommendations to teachers for how much time they should devote to certain topics and activities. The district curriculum office has strongly supported the adoption of the NGSS and efforts towards district adoption such as the supports examined in this research. However, full adoption of the NGSS in the district will likely not occur until the state department of education endorses the NGSS, which, currently, seems a remote possibility.

This research took place within the context of a long-term research practice partnership (RPP; Coburn et al., 2013) called the Inquiry Hub (iHub) of which the aforementioned district is a member. RPPs are long-term, mutualistic collaborations between practitioners and researchers that are intentionally organized to investigate problems of practice and develop solutions for improving district outcomes (Coburn et al., 2013; Penuel, Coburn, & Gallagher, 2013). In terms of the research outlined in this dissertation, the RPP sought to address problems of practice mostly related to building the capacity of the district to adopt the NGSS. The RPP sought to help the district develop, through supporting teacher agency, coherent curriculum materials and implemented these curriculum materials in classrooms to judge their effectiveness for promoting learning students see as relevant and students’ agency. The RPP also examined the implementation of a professional development program, the NGSX, that sought to support teachers in the practice of modeling. RPPs often aim to increase the relevance and usefulness of research for practitioners to support instructional improvement at scale (National Research Council, 2003). In terms of the RPP in this research context, the researchers have dutifully
sought to increase the utility of research, particularly by promoting the use of research-backed design patterns and learning theories within co-design efforts. In addition, the researchers have sought to employ a Design-Based Implementation Research framework (Fishman, Penuel, Allen, Cheng, & Sabelli, 2013; Penuel & Fishman, 2012) to address issues of bringing improvements to scale within the district.

**PURPOSES AND SIGNIFICANCE**

Although the Framework has provided districts with a new vision for science education as carried forward in the NGSS, how districts can best achieve this vision remains a largely unexplored space (National Research Council, 2012). The research reported in this dissertation adds to our understanding of how large educational systems, like districts, may productively go about bringing the vision of reforms like the NGSS into a state of reality via the implementation of supports designed to help do so. Specifically, these three articles provide new insights as to how teachers and students take up supports during implementation in order to mediate their engagement in new forms of teaching and learning called for in the Framework. Each article also seeks to derive practical design principles on how to structure such supports to more productively assist teachers and students in engaging in the sort of teaching and learning the Framework and NGSS call for. A discussion of the specific contributions of each article follows.

**Article 1: Organizing for equitable co-design at the intersection of multiple activity systems.** The first article provides insights on how to promote both teacher learning around the NGSS and teacher agency within a co-design process in order to develop needed curricular materials embodying the vision of science education put forth in the Framework. In terms of insights related to how participants took up supports in their activity, this work showed how organizing for equitable co-design and the use of specific tools, structures, and processes can
promote teacher agency and learning as well as strengthen the end product of a co-design effort. Specifically, this work showed how the use of a skeletal Storyline tool (Reiser, 2013) can support teachers in leveraging their expertise in completing a curricular vision for a unit. In addition, this article showed the importance of organizing participants in small groups during the design of curricular materials to position teachers in taking the lead in the design of materials. Lastly, this article showed how having participants engage in structured critique processes can unearth productive design tensions that can serve as the focus of design. These insights suggest certain design principles for organizing a co-design space geared towards the development of curricular materials, particularly regarding how to optimally design for how participants may take up tools from the design space in their activities, such as a skeletal Storyline. Following from the work of Vygotsky (1934/1978), this article showed consistently how purposefully “under-designing” design tools can promote the productive leveraging of teacher agency in a design process as participants must complete these tools using their own expertise in order to use the tools in design activities.

**Article 2: Relevant learning and student agency within a citizen science design challenge.** The second article provides insights as to how the implementation of a curricular unit with an integrated citizen science design challenge can impart a meaningful sense of agency to students, the capacity “to act (not merely to know)” (Eisenhart, Finkel, & Marion, 1996, p.282) towards something of worth (Lee & Roth, 2003), and can provide students with opportunities to see the relevance of their activity—adapted from Polman's (2012) notion of “senses of authenticity”—to themselves, their class or school, and their community. This study showed that having students take up science and engineering practices to engage in unit activities can support their sense of agency, particularly in the context of activity connected to a citizen science design.
challenge. For designers, this suggests the utility of integrating a citizen science design challenge into formal curricular materials and the importance of positioning students in agentic roles through their engagement with science and engineering practices. In addition, this study found that students may not see their learning generally as relevant to themselves but may still see it as relevant to their community. This highlights the need for designers to attend to different forms of relevance in their curricular materials to promote more meaningful learning for students. Relatedly, this study showed that learning that strongly connects to a citizen science design challenge can lead to students to see those learning experiences as personally relevant but not relevant to their community. This points to the need for designers to consider how the structure of a challenge may influence students’ perceptions of the relevance of a challenge and the need to integrate community involvement.

**Article 3: Implementation of a novel professional development program to support teachers’ understanding of modeling.** The third article provides insights on how the structure and tools embedded within a professional development program, the NGSX, can serve to mediate teachers’ understanding of science and engineering practices, notably the practice of modeling. Specifically, this article showed that during NGSX sessions, the sequence of investigations and the building of specific models, interleaved with discussion activities and video presentations, helped support teachers’ understanding of developing and using models. This suggests the arrangement of activities in the NGSX may provide an effective design pattern for other developers of professional development materials or for those developing curricular materials for teacher learning. In addition, this study demonstrated how tools introduced in a professional development setting can travel to the classroom setting and back again, either through individual efforts of teachers or through formal activities in a professional development
program. For designers, this suggests the need to account for the different means by which tools can travel and how to best leverage these instances for further learning when they occur, particularly for instances of where teachers bring their experiences of classroom implementations back to professional development settings. This study also demonstrated that the ways in which teachers take up tools in their classroom may not align with the intentions of professional development designers, pointing to the need for allowing teachers to have more formal support in implementing tools, such as planning sessions. Lastly, this study showed the importance of the implementation context and how local implementers of the NGSX both supported and hindered the aims of the NGSX. This highlights the need for designers to determine how to optimally leverage the local expertise of implementers while also preserving the integrity of underlying design principles and goals of a professional development.
CHAPTER II

ARTICLE 1
Organizing for Teacher Agency in Curricular Co-Design
by
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ABSTRACT
Cultural-Historical Activity Theory (CHAT) approaches to intervention aim for transformative agency, that is, collective actions that expand and bring about new possibilities for activity. In this paper, we draw on CHAT as a resource for organizing design research that promotes teachers’ agency in designing new science curriculum materials. We describe how CHAT informed our efforts to structure a collaborative design space in which teachers and other
participants sought to develop new curriculum materials intended to help realize a new vision for science education. Specifically, we describe the tools and routines we deployed to support the design process, and we analyze the ways teachers took up elements of our design process as well as how they adapted, resisted, and suggested alternate tools and strategies to help develop new curriculum materials. In so doing, we illustrate ways that CHAT can serve as both a guide for organizing collaborative design processes and for analyzing their efficacy.

**ORGANIZING FOR TEACHER AGENCY IN CURRICULAR CO-DESIGN**

Many education reforms offer visions for what teaching and learning within schools and districts should look like. Reform efforts, however, can fall short because they constrain teachers’ opportunities to contribute their expertise towards achieving such visions (Snow, 2015). Teachers typically encounter these visions as new policies and guidance that circumscribe their autonomy in deciding what and how to teach (Allen & Penuel, 2015; Bryk, Gomez, Grunow, & LeMahieu, 2015). Historically and continuing today, two aspects of teachers’ agency are limited within educational reform efforts, namely their capacity to shape and define the course of the reform effort and their level of control or volition (Konopasky & Sheridan, 2016). This paper describes a strategy for expanding these two aspects of teachers’ agency.

Collaborative design, or “co-design,” in design-based research is one strategy for leveraging the expertise of teachers to design, implement, and test educational innovations and, thereby, expand teachers’ agency within reform efforts. Co-design is “a highly-facilitated, team-based process in which teachers, researchers, and developers work together in defined roles to design an educational innovation, realize the design in one or more prototypes, and evaluate each prototype’s significance for addressing a concrete educational need” (Penuel, Roschelle, & Shechtman, 2007, p. 51). Co-design is inspired by the tradition of participatory design in
Scandinavia, which has long promoted the agency of workers in the design of technologies and practices intended to transform the workplace (Ehn, 1992; Simonsen & Robertson, 2013). In Scandinavia, participatory design is an integral part of efforts not just to promote more usable technologies but also the ideals of workplace democracy, in which workers have a say in initiatives that affect their practice (Kensing & Greenbaum, 2013).

Co-design represents an emerging approach within the learning sciences for producing more usable innovations and for expanding teachers’ agency in the process of improving teaching and learning. Learning scientists have explored co-design’s potential for the design of curriculum materials (Peters & Slotta, 2009; Reiser et al., 2000), interactive technologies (Penuel, et al., 2007; Spikol, Milrad, Maldonado, & Pea, 2009), teacher professional development (Voogt et al., 2015), and strategies for school and district reform (Cobb, Jackson, Smith, Sorum, & Henrick, 2013; Kwon, Wardrip, & Gomez, 2014). Most recently, co-design has become an integral part of community-based design research (Bang, Medin, Washinawatok, & Chapman, 2010) and social design experiments (Gutiérrez & Jurow, this issue; Taylor & Hall, 2013). In these projects, there are many examples of researchers acting as facilitators of co-design who successfully build a context for amplifying teachers’ voices in conversation relative to those of administrators who might otherwise seek to constrain their autonomy (e.g., Penuel, Tatar, & Roschelle, 2004; Voogt et al., 2015).

In this paper, we explore how Cultural-Historical Activity Theory (CHAT; Cole & Engeström, 2006) can be used to theorize, structure, and analyze the co-design process within design-based research. CHAT emphasizes the importance of collective, transformative agency (Engeström, Sannino, & Virkkunen, 2014; Virkkunen, 2006)—the efforts of groups working together to break away from current forms of activity and envision new forms of activity—as the
object of design efforts. As we elaborate below, an emphasis on agency requires learning sciences researchers to attend to three aspects of teacher agency in organizing co-design efforts. First, researchers must organize co-design to provide opportunities for teachers to work together to envision and bring about new forms of teaching and learning, rather than expecting them to work in isolation from colleagues to do so. Second, it demands that researchers consider how the process helps overcome or mitigate constraints to teachers’ professional discretion, which derive from historical and ongoing exclusion of teachers from the design of educational innovations and policies (Ormel, Roblin, McKenney, Voogt, & Pieters, 2012). We take up “history” in design (O’Neill, 2016/this issue, Question 4) not by attending to the particulars of individuals engaged in the process, but with the aim of changing institutionalized relations among teachers, administrators, and researchers that give limited authority to teachers in reform. Third, researchers must attend to the ways that co-design provides specific tools and practices that help teachers break away from current forms of activity in classrooms that limit students’ opportunities to learn. Here, we argue, external visions of reform can provide seeds for teams to imagine new possibilities, but CHAT points to the need for tools for helping develop these seeds into new activities.

In this paper, we address the following three questions:

1. How can CHAT inform the structuring of collaborative design processes in design-based research?

2. How can teachers shape the content of the design and mitigate effects of constraints from their context through engagement with the projects’ tools and routines?
3. In what ways can tools and activities enable teachers to break away from current practice through meaningful engagement with external visions for reform?

Our paper begins with a review of relevant CHAT concepts and methods for organizing collaborative design. We follow that review with an analysis of how we applied these concepts and methods to organize the collaborative design of materials that would embody and further develop an external vision for reforming science teaching and learning (Question 1). Then, we present an analysis of teacher agency in developing the content of the curriculum materials and proposing changes to the design process itself (Question 2), highlighting the ways teachers made use of tools and practices that we, the researchers, provided to foster productive engagement with the external vision of reform (Question 3). Finally, we discuss how our research relates to other design-based research in the learning sciences and to CHAT-informed intervention research and how our approach might be applicable to future design-based research.

**CHAT AS THEORY AND METHOD FOR ORGANIZING FOR TEACHER AGENCY**

Cultural Historical Activity Theory (CHAT) provides both a theory and methodology for cultivating a “shared problem space” (Akkerman & Bakker, 2011, p. 147) in which people can work together to envision and develop new forms of activity. Working together is important, because solutions to educational problems require diverse forms of expertise. A CHAT approach calls for organizing design efforts so that the expertise of one group is not privileged over another and the opportunity to surface potentially fruitful contradictions increases (Gutiérrez, Rymes, & Larson, 1995; Severance, Leary, & Johnson, 2014). Doing so can increase the effectiveness of design teams (Page, 2007). But effectiveness is not the only aim of design within a CHAT approach. A CHAT approach calls for creating conditions in which groups gain new
authority to shape the course of reform and ability to exercise discretion as they move from outsiders to full participants with a stake in defining the object of design (Virkkunen, 2006).

Creating such conditions is not easy within contemporary schooling, because teachers typically have little say over the course of reforms and limited discretion as professionals to shape their own practice in collaboration with colleagues. In contemporary schooling, engaging teachers in collaborative design directly challenges the predominant division of labor, in which policy makers, professional curriculum developers, publishers, and sometimes researchers hold the greatest influence over the design of adopted curriculum materials (Atkin & Black, 2003; Ingersoll, 2003; Tyack & Cuban, 1995). In the current division of labor, teachers have a limited role in design, primarily as “testers” of materials and as actors charged with implementing materials with students in their classroom. This is true even within many design research studies (Ormel et al., 2012). In educational design efforts, teachers’ expertise is often devalued as relevant to a reform; the “wisdom of practice” has a lower status than “evidence” from research (Bryk et al., 2015). Thus, the organization of the design process itself must take into account the historical inequities that characterize the schools and communities where designs will be developed and tested (Bang et al., 2010; Penuel, et al., 2004).

The approach also demands that researcher-interventionists create conditions for the emergence of what CHAT researchers refer to as transformative agency (Engeström et al., 2014; Virkkunen, 2006). Transformative agency is collective action both to break away from current forms of activity and to develop “new concepts that may be used in other settings as frames for the design of locally appropriate new solutions” (Engeström, 2011, p. 606). The aim of intervention is not to help individuals change in relation to static, unchanging forms of activity. Instead, it is to bring about new activity systems, that is, new relations among the components of
human activity, including its tools or artifacts, rules, and division of labor (Engeström, 1987, 2011; Engeström et al., 2014). Further, CHAT asks design researchers to consider “implementation” not as a phase that follows design but an integral aspect of it (Engeström, 2009).

This stance contrasts with typical ways teachers’ responses to external reforms are interpreted. In most reform activity, the “resistance” of teachers is seen as a problem, but in CHAT intervention, resistance is a valued resource (Sannino, 2010). Even when teachers’ individual resistance to change focuses on individual problems but not the larger systemic context that creates them, explicitly discussing such resistance can be an important first step to making the development of new forms of activity a “personally meaningful object” (Virkkunen, 2006, p. 52). Co-design must seek to go beyond such acts of resistance, though, in enabling teachers themselves to engage in “transformative action” (Voogt et al., 2015, p. 262). That is to say, co-design must be organized in such a way as to enable teachers to commit to and engage in actions that reflect personally meaningful goals and that result in new forms of activity in their classrooms.

Accomplishing the aim of creating conditions for working together productively to envision and bring about new forms of activity in schools is a tall order. CHAT points to the central importance of mediation in human action. Vygotsky (1987) first highlighted the role of what he called “psychological tools” as means linked to the higher mental functions of directing attention, constructing memories, and solving problems. For him, such tools included signs and systems for creating and transforming meaning: language, gesture, systems for counting, mnemonic devices, mathematical symbol systems, diagrams, maps, drawings, and so forth. The introduction of such tools into the flow of activity both facilitates and transforms object-oriented
activity. Below, we elaborate on the implications of Vygotsky’s method for analyzing the role of tools in mediating human action, the method of double stimulation, as a key conceptual resource for organizing collaborative design using CHAT.

The Method of Double Stimulation: Tools and Routines for Organizing Co-Design

CHAT theorists have always been concerned about how to study and support the efforts of human beings to change their worlds and, thereby, to change themselves. Vygotsky’s (1934/1978) method of double stimulation was an early attempt to study how experimental subjects made use of available tools in their environment to complete tasks presented to them by experimenters. In this method, Vygotsky would first present a task to the study participant (e.g., “Memorize this series of pictures”). Then, rather than observe how the participant attempted to perform the task on their own, Vygotsky would provide the participant with a set of tools that could be used to help solve the task (e.g., a pencil and paper). The task and the means by which it could be solved constituted the two stimuli (Valsiner & van der Veer, 2000; van der Veer, 2008).

Vygotsky highlighted the need to focus on what artifacts the participant chose, viewing the experimental subject as “an active agent who selects for his own use whatever objects or tools are available” (van der Veer, 2008, p. 22). He also indicated that the tool selected as the second stimulus should be “neutral,” though he did not define what might count as a neutral stimulus other than to say that “when difficulties arise, neutral stimuli take on the function of a sign” (Vygotsky, 1934/1978, p. 74) that is meaningful to the participant as an aid to problem solving.

An adapted form of Vygotsky’s methodology of double stimulation guides Engeström and colleagues’ (Engeström, 2007; Engeström, 2011; Engeström & Sannino, 2010) approach to formative intervention research, an approach called the Change Laboratory. In contrast to the situation where an experimenter puts a single participant into a position where a defined problem
already exists, in the Change Laboratory the task or first stimulus is something that a group of participants defines collaboratively. As Engeström (2011) writes, participants “face a problematic and contradictory object, embedded in their vital life activity, which they analyze and expand by constructing a novel concept, the contents of which are not known ahead of time to the researchers” (p. 606). As in Vygotsky’s approach, it is the participants who select, adapt, or invent the means of solving the problem. But in the Change Laboratory, there is no ready-made solution that the researcher has devised; rather, “the contents and course of the intervention are subject to negotiation and the shape of the intervention is eventually up to the participants” (Engeström, 2011, p. 606). Intervention facilitators, who are often the researchers, expect that proposals for solutions to problems will be met with resistance, as proposals are always “loaded with affects, hopes, fears, values, and collective intentions” (Engeström, 2011, p. 611). As such, they are not “neutral” but rather “ambiguous” in that they are at first general ideas rather than fully developed concepts with implications for action. In the Change Laboratory, the researcher’s role is that of a provocateur and facilitator, rather than someone who directs activity toward a solution that has been defined in advance.

Sannino’s (2010) analysis of teacher responses to a Change Laboratory she facilitated in an Italian school provides a good example of how contemporary CHAT theorists have applied the method of double stimulation. The principal of the school and a teacher representative asked Sannino to provide professional development on formative and summative assessment. Sannino proposed a Change Laboratory instead, and the two agreed. In the initial phases of the Change Laboratory, a different focus for the work was established: teachers found it difficult to manage their classes while conducting the traditional individual oral assessments required of all students. Initially, some teachers resisted addressing this problem at all, but eventually “a different way of
talking about change emerged, involving the taking of individual and collective initiatives for small-scale changes and innovations” related to student assessment (Sannino, 2010, p. 841). This approach illustrates how conditions can be established through the Change Laboratory for teachers’ resistance to external demands of administrators to be taken up productively (as opposed to dismissed or ignored) to imagine new possibilities for action in a school context. It also underscores why CHAT theorists (Sannino, Engeström, & Lemos, this issue) sometimes refer to the method of double stimulation as a principle for volition and agency, since the volition of teachers is recognized and agency of teachers expanded through the use of the method.

To date, there has been limited engagement with ways that the method of double stimulation might be adapted fruitfully to incorporate specific ideas and tools from the learning sciences into the process of collaborative design of curriculum materials. Danish (2014) recently explored how activity theory could be applied to the design of a sequence of instructional activities focused on teaching complex systems, and he proposed that learning theories could be important mediators of the design process. Likewise, Penuel (2014a) has proposed that local instructional theories are potentially important tools in design. To date, however, research has not explored how such tools might mediate collaborative design processes, or what other tools might be necessary to create the conditions for expanding teacher agency in the ways that CHAT demands. The current study aims to address this gap in the research.

THE CURRENT STUDY

In this section, we describe the design of a collaborative design research project called the Inquiry Hub (iHub). This design effort took place within a longstanding research-practice partnership (Coburn, Penuel, & Geil, 2013) that is focused on supporting teachers within the partner district in developing student-centered approaches to curriculum and teaching. In this
particular project of the partnership, a team comprised of researchers, district level
administrators, and teachers has been developing and testing the efficacy of new curriculum
materials in science education with funding from the National Science Foundation. First, we
describe the participants in the design research, then the specific project focus and time span, and
finally our methods for studying teacher agency in collaborative design.

Participants

In our project, a total of sixteen secondary school science teachers have participated in
the design process, seven of whom have also pilot tested the curriculum materials we co-
designed. Of these sixteen secondary school science teachers, twelve participated actively
throughout the project. The teachers’ level of classroom experience ranged from those beginning
their second year of teaching to those with over twenty-five years of experience; on average,
teachers had twelve years of classroom experience. In addition to the core teacher group, the
project had the active engagement of five district level administrators from the partner district’s
curriculum office, six members from community stakeholders such as the local parks and
recreation department and the US Forest Service, two curriculum writers from the Biological
Sciences Curriculum Study (BSCS), six university researchers, and two members from the
University Corporation for Atmospheric Research (UCAR), a large research non-profit.

Focus and Time Span of the Design Effort

The focus of this particular co-design project was on developing and testing a new unit
on ecosystems that addresses performance expectations outlined in the Next Generation Science
Standards (NGSS Lead States, 2013), a set of standards developed from A Framework for K-12
Science Education (National Research Council, 2012). The development process was organized
both as an opportunity to produce usable, engaging materials for the classroom and as an
opportunity for teachers to learn through developing those materials. In line with our proposed
design framework, we organized the design space to promote a more equitable arrangement
amongst participants and to foster ownership of the process by teachers.

The description of the design process within this paper focuses on the first year of the
effort, which the iHub research team initiated with a weeklong workshop that included teachers,
district leaders, curriculum developers, and our research team. The design process continued up
and through the initial piloting of the materials by teachers through a series of periodic face-to-
face meetings and virtual meetings (via the web conferencing system, Zoom). In all, participants
put in more than 100 hours of joint work to design materials for the ecosystems unit. Research
assistants, curriculum developers, teachers, and district leaders were all paid for their
contributions.

Methods for Studying Teacher Agency in Design

Our approach to analyzing collaborative design is primarily ethnographic, focused on
developing an understanding of how participants acted together to develop new curriculum
materials and make meaning of their participation in the process. It draws on interpretive
perspectives on how people constitute local activity settings and is part of a growing tradition of
using ethnographic methods to study design processes in the learning sciences (e.g., Barab,
Thomas, Dodge, Squire, & Newell, 2004; Jurow & Shea, 2015). That is, we focus on how it is
that people participate in and make sense of their participation in design activities.

We relied on multiple sources of data to construct our account of teacher agency in
design. Our primary source of data was a set of ethnographic field notes from observations
conducted as part of approximately 20 hours of whole-group collaborative design sessions. Other
sources were free-write reflective essays from seven teachers written at the conclusion of the
initial design workshop, feedback surveys from 11 teachers as part of embedded critique activities (described in detail below as part of our design process), and online surveys completed by 11 teachers at the midway point of the co-design process. See Appendix A to examine the surveys administered. We also reviewed the 37 lessons written by participants to develop interpretations of our co-design process.

CHAT provides the framework we used to analyze these data. We sought to identify evidence of transformative agency in the actions of teachers recorded in our data sources and to characterize when and how transformative agency arose within the design process. As such, we focused on evidence in the form of actions taken to influence the shape of curricular materials and the design process itself. Specifically, we sought evidence into whether or not our design approach supported teachers in facilitating a “breaking away” from earlier patterns of activity, either in terms of realizing in practice the vision of the Framework or in terms of re-mediating historical inequities between researchers and teachers. Accordingly, we focused especially on interactions within the whole group in design meetings, because we sought to document the development and coordination of teachers’ collective agency. In our case, we interpret the co-design process as the primary site for “collective action.” We imagine the systems of activity that are transformed through the actions of participants to entail both those of classrooms, in terms of achieving the vision for science education called for in the Framework, and the partnership itself, in terms of achieving a new form of design activity that empowers teachers and privileges their expertise.

**HOW WE ORGANIZED FOR TEACHER AGENCY IN THE INQUIRY HUB**

In this section, we describe how we employed CHAT to organize the co-design process to expand teacher agency within a reform effort within the iHub project. Our intent in focusing
on the design process is to contribute to a more refined theory of collaborative design, to which we return in the concluding section of our paper.

**The First Stimulus: Presenting the Vision of A Framework for K-12 Science Education**

In Vygotsky’s method of double stimulation, the “first stimulus” is a task that the researcher presents to a participant to accomplish. In our case, that first stimulus was a vision for the improvement of K-12 science education, *A Framework for K-12 Science Education* (National Research Council, 2014) and a charge to design a curriculum unit that embodied its principles. We did not define the content or flow of the unit ahead of time. The participants to whom this vision was presented were the design team teachers. The researchers and district leaders who were part of iHub had decided on this first stimulus ahead of time. We note that this approach departs from how Engeström and Sannino (2010) describe their application of Vygotsky’s method of double stimulation, because in their approach, participants jointly negotiate the object or first stimulus. Our process, thus, seeks to illustrate how co-design may support teacher agency, even when the initial first stimulus for action is external to the collaborative design team.

During an initial 5-day design workshop, we presented the first stimulus as both an ambitious and ambiguous task: to design a curriculum unit that teachers would want to teach to their students while showing integrity to the vision for improving science education as defined in the *Framework*. Given that the *Framework* is a vision, that is, an image of what science education could be, and not a fully realized system of science education, we sought to create opportunities for teachers to exercise agency and leverage their expertise in creating a functional interpretation of the *Framework* as realized in the form of a tangible curriculum unit. As no one knew the form of the unit ahead of time, participants had the opportunity and challenge of negotiating its shape while showing integrity to the vision of the *Framework*. As such, we
followed this presentation with a series of activities in which the entire team had opportunities to interpret the vision of the *Framework*, participate in learning activities that aligned to the vision, and “unpack” (Krajcik, Codere, Dahsah, Bayer, & Mun, 2014) specific performance expectations of the Next Generation Science Standards (NGSS Lead States, 2013). Teachers could and did challenge aspects of the vision of the *Framework*, and we made efforts to surface concerns teachers had with different aspects of the vision and with implementing it.

In our initial presentation of the first stimulus, we highlighted several elements of the vision of the *Framework*. The key principles emphasize that children are born investigators, that science is both a body of knowledge and set of practices for generating knowledge, that student understanding develops over time, and that science education should build on students’ interests and experience. The *Framework* articulated a “three-dimensional” view of science proficiency, in which developing understanding of a few disciplinary core ideas is posited to go hand-in-hand with students’ engagement in science and engineering practices and their making connections to “crosscutting” concepts across different science domains. The vision of the *Framework* also included a strong focus on equity and the sources of inequity in American schooling. We emphasized in our presentation that the *Framework* identifies inattention to what motivates and fails to motivate students from different backgrounds as a key source of inequity that led the authors of the *Framework* to call on educators to employ a wider range of strategies for “build[ing] on students’ interests and backgrounds so as to engage them more meaningfully and support them in sustained learning” (National Research Council, 2012, p. 283).

From our perspective, presenting this vision and task was a “prologue” and differs from what is typically the first step in formative intervention research, the confrontation of dilemmas and contradictions within and between activity systems. We neither expected nor hoped that
teachers would simply “accept” the vision of science teaching and learning in the Framework or their charge to develop materials aligned to it. Rather, we introduced the Framework in the same spirit that CHAT intervention research confronts participants with a challenging problem. We intended it as a provocation, and we expected resistance to both the vision and the charge along the way.

**Small Group Structure: A Tool for Leveraging Distributed Expertise in Working Together**

To facilitate the leveraging of teachers’ expertise, we structured activity to occur in small teams to increase the opportunities for teachers to directly contribute to the design and achieve a more equitable division of labor. Because of the large number of participants and varied experiences of researchers, teachers, curriculum writers from BSCS, and district leaders, we also anticipated that it would be more efficient to create smaller teams.

Teachers self-selected into small groups based on their interests in particular science phenomena that would be explored in the unit. In each group, we sought to ensure that teachers comprised at least half the membership of each group with the rest made up of researchers, curriculum writers from BSCS, members from UCAR, and district administrators. This simple move, we posited, would enable teachers to have much more say about the content of the unit. The authority of how to leverage expertise would become distributed across the design space and allow for a more horizontal arrangement of expertise and the meaningful leveraging of that expertise in the design.

Throughout the course of the design work, small groups alternately worked on their own, where they decided how to develop lessons for their section while being cognizant of work occurring in other groups, and with the whole team. To facilitate coordination between different teams during the design process, researchers and district administrators also embedded
themselves within each small group. Researchers and administrators intended to absorb the task of organizing small group work in order to enable teachers, who typically have significant demands on their time during the school year, to be in a better position to focus on their ideas for the unit and to take the lead on developing lessons.

**The Storyline Tool: A Second Stimulus Supporting Organizing for Agency**

Because the *Framework* provided a vision rather than a detailed map to support new ways of promoting science teaching and learning, we needed other mediating tools and processes to interpret the *Framework* and for designing specific instructional resources. A key tool we used throughout our collective design work was the *Storyline*, developed by Reiser (2014). Reiser developed the *Storyline* tool to support the development of coherent, well-sequenced units as called for in the *Framework*, that is, a curriculum unit that is “logically organized, integrated, and harmonious in its internal structure” (National Research Council, 2012, p. 245). The *Storyline* tool also attempts to embody principles for project-based learning derived from decades of design research on science curricula, including such principles as driving questions that provide a structure for a sequence of student activities, and engaging students in authentic practices of the disciplines (Blumenfeld, Soloway, Marx, Guzdial, & Palincsar, 1991; Krajcik & Blumenfeld, 2006; Marx, Blumenfeld, Krajcik, & Soloway, 1997; Polman, 2000).

It is important to note that this was the first time the *Storyline* tool had been used to design curriculum. It was developed from Reiser’s involvement in design-based research efforts to develop coherent science curriculum units organized around driving questions. As a tool for designing curriculum units that embodied the principles of the *Framework*, it was untested.

The key elements (depicted in Figure 1 below) of the *Storyline* tool are a series of components that design teams are to complete prior to developing individual lessons. The tool is
intended not just to help organize the flow of instructional activities into a coherent whole, but also to ensure that students are engaged in science practices to “figure out” things that can help them answer the unit’s driving question or to solve its overarching design challenge.

![Blank Storyline Tool](from Reiser, 2014; PE = Performance Expectation).

In our initial design workshop, we proposed using the Storyline tool as a means to promote coherence for the ecosystems unit overall, as well as for sub-parts of the unit. We proposed using it for sub-parts because we believed our team was too large to develop lessons as a “committee of the whole,” and yet we were concerned that each part should have a logical flow and connect with the overall storyline for the unit.

Notably, the structure of the Storyline tool embodies the characteristics of a secondary stimulus and we sought to leverage it within the design process to promote teachers’ agency as such. Like any tool, the Storyline tool has an expertise embedded in its structure that facilitates the completion of tasks. In this case, the structure of the Storyline reflects the Framework and research on science curricula, and it serves to facilitate design work. The Storyline tool, however,
still has a “skeletal” (Engeström, 2011, p.621) structure and has an inherent ambiguity, in that it
does not come fully formed or pre-filled for use in the design space. Instead, participants in the
design space must decide how to fill in the Storyline tool and how to imbue it with their own
meanings as they pursue the object of design (i.e. a new unit embodying the vision of the
Framework). It invites participants to decide on the science phenomenon and driving question
that will anchor a unit and that students will investigate, the specific science practices in which
students will engage, and the particular components of a performance expectation (related to a
“Standard”) that will be addressed. Teachers must leverage their own unique classroom and
content expertise in completing this tool. Doing so may increase teachers’ agency as they have
increased their own capacity to influence the design of materials by bringing additional
expertise—their own—to the design.

Critique Routine: A Tool for Coordinating Expertise

We also integrated structured “critique routines” into the collaborative design space.
Purposefully seeking to better leverage teachers’ expertise and foreground their voices in the
design space, we sought to develop routines for fostering critique and design for teachers to have
the opportunity to take on an empowered role—that of an evaluator or critic of the emerging
design. We also designed these routines to be taken up by participants in ways that could serve as
a mechanism for coordinating the work across the small groups.

These critique routines included two structured feedback events. These events required
each group to present the lessons they had developed for the ecosystems unit. Other teams in
attendance, as well as other participants from community stakeholder groups (e.g. parks and
recreation department), would then provide immediate feedback during whole group discussions.
We also employed in-session surveys to promote equitable participation so that all participants
could have the opportunity to provide feedback regardless of their level of participation in discussions. In addition to integrating the structured critique events, the research team also distributed online feedback surveys to teachers at key junctures throughout the design process, namely immediately after starting the design process, mid-way through the design process, and prior to the piloting phase of the curriculum. In this way, we could collect and respond to targeted concerns from teachers in a timely manner.

ANALYSIS OF TEACHER AGENCY

In the previous sections, we described our approach to organizing the design space so as to promote teachers’ agency, using specific tools, routines, and structures. In this section, we present an analysis of how those teachers engaged with these elements of our design approach. Our aim in this section is to examine whether, and to what degree, teachers exercised agency in the design process. Our method of analysis centered on identifying evidence of transformative agency, in other words, instances of a “breaking away” from previous patterns of activity to achieve new forms of activity, hopefully forms that were valued by participants. On the basis of this analysis, we make two claims: 1) The design process occasioned teachers’ agency around the structure and content of the curricular materials, resulting in significant and lasting changes to curricular materials, and 2) The design process occasioned teachers’ agency around the structure of the design process itself, resulting in significant and lasting changes to the design process. To support these two claims, we present our analysis as a series of claims accompanied by data presented in narratives we have constructed of the design process to allow the reader to judge the significance of the changes observed and the mechanisms that we propose account for their occurrence.

Evidence of Agency in Determining the Structure and Content of Curricular Materials
In seeking to move towards the externally provided object of the vision for science education called for in the *Framework*, teachers’ actions shaped the structure and content of the ecosystems unit. Specifically, teachers played an integral role in the selection of the anchoring phenomenon and driving questions that provided an overarching structure for the unit; teachers, working in small groups, determined the content and shape of individual lessons; and teachers leveraged ideational tools such as the notion of coherence and moving beyond “trust me science” when evaluating curricular materials. Together, these informed changes in the unit’s structure.

**Selection of an anchoring phenomenon for the unit.** For the teachers on the design team, both selecting a single curriculum “anchor” and organizing their own sequence of lessons around that anchor were new planning activities. The teachers on the design team either taught biology using the district’s adopted textbook, *BSCS Biology: A Human Approach* (Biological Sciences Curriculum Study, 2006) or used materials they found that aligned with individual state standards. Although *BSCS Biology* is grounded in an instructional approach consistent with findings from learning sciences research (Bybee et al., 2006), the text was not organized around a single anchor. Thus, our co-design work was organized to help teachers break away from current routines in the way they interacted with curriculum materials, towards a vision more closely resembling that of the *Framework*. Below, we provide evidence that shows how teachers and others exercised agency that resulted in choosing a phenomenon to anchor the unit.

Early in our first design workshop, teachers on the team got a chance to use the first part of the *Storyline* tool to make suggestions about and select the anchoring phenomenon for the ecosystems unit. The first step in this process was a whole-group brainstorm of possible anchors for the unit, facilitated by the second author. Teachers began sharing both possible phenomena and driving questions. The first offered by a teacher was a driving question, “Why can’t you
drink water from the Platte river?” Another suggested focusing on the question, “What’s killing the trees?” This question referred to the devastating impact of the mountain Pine Beetle on native lodgepole pine forests. Other teachers suggested, “Why do animals go extinct?” and “How does dog poop affect our community?” The latter question prompted participants to acknowledge that phenomena that occur in urban ecology settings should be preferred over mountain ecology settings for as one teacher commented “Right, we don’t have mountains.” Teachers (with facilitators pushing for specificity) suggested more location-based, urban ecology phenomena such as “How does development affect Prairie Dogs?” Following a teacher’s suggestion of “How do trees in the world affect me?” the first author suggested, citing a local tree-planting initiative, “Why should I plant a tree in my neighborhood?”

Following the brainstorm session, the design team broke into three separate groups to dig deeper into aspects they would need to consider in selecting a phenomenon. One group analyzed the NGSS science and engineering practices related to the performance expectations for ecosystems in the NGSS in order to get a sense of what the NGSS expects students should have the capacity to demonstrate at the end of the unit. Another group focused on student interests and connections, specifically, what sort of phenomena and questions students would find engaging. The final group examined educational research pertaining to impediments students typically encounter when learning about ecosystems concepts. After working in their small groups on their respective tasks, facilitators then reformulated groups so that each new group had members from the previous three, allowing each group to have access to the expertise of the previous groups. Each of these new groups then engaged in developing an argument for which two phenomena—chosen from those “brainstormed” previously as a whole group—they believed would provide the most ideal means to anchor the ecosystems unit.
Each group presented their proposals to the whole group for review which led to participants engaging in discussions of whether “phenomena/questions” should anchor the unit and what such a unit would entail. A teacher from the first group presented a single proposal, the “planting of trees, the ecological issues that surround tree planting,” an endorsement of the question, “Why should I plant a tree in my neighborhood?” from the “brainstorm.” The teacher also shared their driving question for this phenomenon: “If you plant a tree, one tree, themselves, will it make a difference?” A teacher from this group suggested that the phenomenon could be, “The city advertises that they give away free trees.” The lead facilitator responded, “Is that a scientific phenomenon to be explained though?” Seeking to provide support that some form of the phenomenon actually could serve as a scientific phenomenon, participants from the second group—who had also selected this same phenomenon/question—shared part of a report a teacher in their group had found of how tree cover positively correlates with the health of an ecosystem and how “if the city increased its tree cover by 25% the environmental and economic effects would be substantial.” Intrigued by the idea, but wanting to know more, another teacher questioned, “So, what is ‘substantial?’ What are the ‘economic effects?’ What are the ‘environmental impacts?’”

The group continued to engage the possibility of focusing on the role of tree planting and tree cover, proposing different ways to word a driving question for the unit that highlighted different aspects of this potential phenomenon. A district administrator suggested, “I see a new neighborhood of houses going in, they’re taking away all the trees, is that a good thing?” This spurred the lead facilitator to re-phrase the district administrator’s re-phrasing of the phenomenon as “A change brought about by humans in the local ecology has an impact on the ecosystem.” Pointing to the group’s presentation, the facilitator declared, “This is our way in, to
explore almost the reverse of that.” Not challenging this re-phrasing, a teacher in the first group made the case that the exploration of the proposed phenomenon could touch upon numerous disciplinary core ideas. In addition, this teacher also suggested a culminating project of “urban planning, pulling in some engineering,” where students could “design something” in their communities.

Like the first group, the second group had also chosen, independently, the phenomenon/question relating to tree planting. Echoing the teacher’s comments from the first group about “urban planning,” this group suggested the phenomenon be an engineering challenge focused on “designing a solution” to a real problem. In presenting their proposal, a teacher explained that they focused on envisioning “If I was a student, what would I need to know about. Why should I plant the tree? Where should I plant the tree? How close to other trees should I plant it? In what area should I plant it?[...] the city gives you a tree to plant. What do you do?” This group also sought to have students examine the impact of planting trees “on a local, global scale.” Other participants seemed encouraged by this approach, which one of the researchers labeled a “design-centered” phenomenon. This researcher saw possibilities in having students examine evidence in the report a teacher in the group had found that had spurred their design-centered tree-planting proposal.

The second author then asked the group, “Do people see the possibility of blending these two ideas into a single one?” Several teachers provided their opinions on how the two proposals could complement one another, with most seeing the design-centered approach of the second group as providing a motivating challenge for students within which the specificity to disciplinary core ideas of the first group could become embedded.
The third group to present chose a different phenomenon/question from the previous two groups for their proposal. A teacher from the third group began their presentation by sharing their phenomenon, “wild animals are seen in the city”—which specifically built on a phenomenon/question on the presence of foxes in cities from the “brainstorm”—and shared their driving question, “Why are they there?” Reiser then explicated a partially completed Storyline representation using their chosen phenomenon as an anchor. During this presentation, participants from other groups sought to find opportunities for integrating and building on ideas presented in this group with other groups. For example, one teacher from the second group, pointing to the third group’s Storyline representation, offered, “I actually think that, if we’re combining the two tree ideas, that the one we built, our flow diagram has a lot of those questions that we just need to put in.”

The group deliberated next about the merits of having one or two different units, each with a different anchoring phenomenon. Different teachers voiced different ideas, with some arguing that two phenomena would sustain student interest better than one, while others worrying that there would not be enough time to teach two units. At an impasse, facilitators split participants into two groups with each developing a culminating performance assessment for one of the two possible phenomena/questions. After groups presented their work back to the whole group, the lead facilitator determined, and others agreed, that each phenomenon/question would take up all of the 8-weeks allotted for the unit; therefore, choosing one, as the lead facilitator put it, “in order to move forward” had become necessary. Initially the lead facilitator asked for participants to come back the next day to make their final arguments but a teacher instead insisted that “I don’t think we need to argue [...] none of us are married to foxes.” Checking with
other participants, the lead facilitator asked, “So, I’m hearing trees?” No participants voiced disapproval to the motion. “Okay, let’s go for it,” said the facilitator.

Although the exact language of the phenomenon shifted over the course of the next several weeks to “humans modify their ecosystems through the practice of tree planting,” the main kernel of the phenomenon/question that the participants agreed to at this initial design workshop did become the permanent anchor for the ecosystems unit. In addition, the idea of having students “design something,” to engineer their urban environment, as suggested by the teacher in the first group and which served as the structure of the second group’s approach, also was taken up permanently in the unit. Specifically, this element became the driving question for the unit’s design challenge, in which students would figure out What tree should we plant and where to maintain the services our ecosystem provides?

This extended episode demonstrates how teachers’ agency influenced the selection of both the anchoring phenomenon and driving question for the unit. It shows how teachers took action towards organizing the unit around an anchoring phenomenon and driving question, an orientation aligned to the vision of science education in the Framework. We also saw in this example how agentic acts can interlock and build on one another. This interlocking process of agentic acts proved common during the design workshop and demonstrated the importance of having teachers’ agency as a “link in the chain.” In addition, we see here how participants engaged with elements of our design process (e.g. small groupings, critique sessions, Storyline tool), both separately and in combination, to move the design forward.

Teacher teams’ determination of content and flow of individual lessons. Teachers not only contributed to determining the overall anchor for the unit, they also determined the content of individual lessons, as well as the flow of those lessons. Here, we provide evidence that
demonstrates how teachers, within their small groups and through the taking up of other elements of our design approach, exercised agency to shape the content and flow of individual lessons.

Towards the end of the initial 5-day design workshop, the facilitators asked participants to form small groups where each group would commit to developing lessons for one of the four sub-questions within the Storyline diagram. Each of the four groups consisted of two to three teachers and one to two group facilitators, who were either researchers or curriculum specialists at the district. Before leaving the workshop, facilitators tasked each group with completing a “team charter,” a collective agreement among group members over how to divide up the labor of creating the lessons relating to their sub-question and a schedule their work would adhere to. Over the next five months, the groups met regularly to develop the individual lessons that would eventually comprise the ecosystems unit.

In developing their lessons, individual groups continued to use the Storyline tool developed at the 5-day workshop to organize their own work and coordinate with the work of other groups. Each team was responsible for elaborating upon lessons related to a “row” or sub-question that they took ownership of (see Figure 1), yet each group still had to determine (1) which science and engineering practices students would use in order to explore their particular sub-question and (2) what understandings of disciplinary core ideas students would build around their sub-question that would lead naturally to the next row and sub-question in the Storyline diagram, or, in the case of the final group, would lead to a culmination of the unit. Initially, each group worked independently to figure out how to organize a sequence of lessons lasting roughly two weeks.
A close analysis of one group’s efforts illustrates the ways in which teachers exercised agency in small groups to influence the content and flow of individual lessons. This group was referred to as “Group 4” because their task was to develop the last of four parts of the unit. Initial work within this group focused primarily on determining how to effectively fill in their assigned row in the Storyline diagram. The group believed that doing so would ideally provide them with a clearer idea of how to develop actual lessons that engage students in using science and engineering practices to explore their sub-question and build relevant pieces of the disciplinary core ideas and crosscutting concepts. Much of the design work at this stage in Group 4, therefore, consisted of proposing and evaluating lesson ideas. For example, one teacher had proposed using existing materials to create a lead-in lesson looking at how humans can negatively impact the services ocean ecosystems provide. Another teacher questioned whether such a lesson fit coherently within the group’s section and the unit. Compromising, the teachers decided that the lead-in lesson would need to address forestry and tree ecosystem resources more directly.

After evaluating and critiquing potential approaches for their lessons and deciding on what they believed would be the most viable ideas, Group 4 began to consolidate their ideas and record them within the Storyline tool. Doing so required members of Group 4 to reach agreement on numerous aspects of the lessons, such as the content and instructional approaches the lessons would employ. For example, teachers had to agree on the format of the final culminating product students would produce, as the product provided students with a common thread throughout all the lessons in this section. Teachers agreed that the final product would require students to work in small groups from start to finish (rather than work individually), and students would present their conclusion about what tree to plant to the class (rather than simply submit a report to the
teacher). Each group, the teachers decided, would have to make an argument for how planting a specific species of tree in a specific location would best maintain the services and stability of their urban ecosystem. Referencing the Storyline tool and the NGSS, the teachers felt that such an approach would require students to engage meaningfully in science and engineering practices, in this case engaging in argumentation from evidence, to explore and leverage disciplinary core ideas students had developed throughout the unit.

With a draft of their row in the Storyline tool complete, members of Group 4 then went about the work of actually bringing their collective vision for their section of the unit into being. After negotiating what would constitute a fair but realistic workload amongst the group members, each member agreed to write a sequence of two or three lessons. This approach, teachers felt, would also best maintain coherence across lessons, with set chunks of lessons coming primarily from the same lead authors. Using a common lesson plan and slide template, each member slowly developed lesson materials for classroom implementation. At scheduled time periods, Group 4 reconvened to share their progress with one another and evaluate each other’s work. At one such meeting, a teacher floated the idea of having students collect field evidence necessary for making their final argument digitally using their phones, rather than using more traditional paper-based field notes. This idea gained traction and became reality after further collaborations between Group 4 members and computer scientists at UCAR. Teachers showed palpable excitement at the development of a technological tool for recording evidence students would need to support their argument, with one teacher commenting, “I can’t believe they actually made it. It’s real.” Teachers felt that utilizing technology in this way to collect data would allow students to have a deeper engagement with science and engineering practices such as developing and using models.
Not all groups structured participation in the same way as Group 4 did to allow teachers to lead the writing of lessons. Although members of Group 4 negotiated a division of labor that they deemed an equitable distribution of the workload, with teachers taking the lead authorship of chunks of lessons, other groups did not do so. For example, in Group 1, a researcher served as the lead author on 6 of 7 lessons. In Group 3, a curriculum writer from BSCS served as the lead author on 6 of 11 lessons. Only in Group 2 did teachers serve as lead authors on all 7 lessons. In Group 4, described above, teachers contributed the majority of lessons, serving as lead authors on 7 of 12 lessons.

This section provides an illustration of how teachers exercised agency that led to lasting effects on the content and flow of individual lessons, but we also provide evidence that their agency in developing lessons varied across groups. At a fundamental level, each group’s completion of their lessons provides evidence of tangible attempts to achieve the vision for science education in the Framework, yet variation from group to group regarding the proportion of lessons teachers took the lead in authoring calls into question how much influence they had in shaping lessons. In terms of the design process, the small group structure, in concert with the use of the Storyline tool, seemed to facilitate the work of Group 4. Members of Group 4 credited the ability to work out their ideas in a small group and that they were collectively committed to the effort as important factors in their productivity.

**Teachers’ appropriation of content-related ideational tools.** In Vygotsky’s method of double stimulation, analysis focuses on whether and how participants take up or use tools introduced by the researcher. Here, we present a similar type of analysis, focusing on the ways that teachers took up key ideas introduced as tools for designing coherent units that embodied the “three-dimensional” vision of science learning presented in *A Framework for K-12 Science*
Education (National Research Council, 2012). We found strong evidence of appropriation of two key ideas by teacher participants, in ways that we, the members of the research team, could not have anticipated ahead of time.

One of the facilitators introduced both ideas during the second day of the initial 5-day design workshop. One was a contrast between what he called “trust me science” and giving students the opportunity to “figure out” core science ideas. In trust me science, “the teacher does the lab, then teaches the idea so kids understand what they just saw” (Reiser, 2015, p. 22). By contrast, in “figuring out science,” the central aim is for students to develop models that explain phenomena rather than just “learn about” them. A second idea was that of coherence, which is central in A Framework for K-12 Science Education and is an aim the Storyline tool seeks to support. According to Reiser (2015, p. 25), when lessons are organized into a coherent storyline, “investigations are motivated by questions from phenomena, not [the] order of topics in [a] textbook.”

There were multiple examples of teachers taking up the language of and distinction between “trust me science” and “figuring out science.” For example, at the conclusion of the 5-day design workshop, one teacher described what he had learned during the workshop in the following way: “Lessons should be built around students’ need to know to make sense of phenomena. We tend to use various less effective teaching strategies, including ‘trust me’ and ‘look at this cool thing!’ strategies.” Similarly, other teachers saw the notion of “trust me” science as an important means for making design decisions early on in the design process. One teacher commented at the conclusion of the 5-day design workshop “we may be veering towards our comfortable zone too much and we need a list of non-negotiables - like the ‘trust me’ and how to solve that when it comes up.” Teachers also drew on ideas related to the notion of “trust
me” science, particularly when evaluating lessons within the unit. For example, during a face to face design meeting, Group 2 presented their ideas for their section of the unit to the other groups. Their lessons made heavy use of previously developed materials, particularly a lab that had students collect data on oxygen and carbon levels within a container filled with select organisms. One teacher critiqued the group’s lessons, citing that the “activities suggested seem to be ‘demonstrations’ as opposed to inquiry labs.” While not directly referencing the notion of “trust me” science, this teacher showed concern that the materials presented placed students in a passive position and did not meet the main goals of the design effort, which this same teacher described as to “incorporate NGSS into [the design] which are some higher learning skills and higher kind of inquiry and the idea of having the kids solve the problems and having the kids go out and figure out the learning kind of on their own.”

Some participants also took up the second key idea, coherence, as a filter for evaluating the fit of lessons to the anchoring phenomenon. During a face to face meeting in the fall where each group presented in-progress work pertaining to their section in the Storyline, for example, teachers leveraged their understanding of the notion of coherence to alter the structure in the Storyline, and hence the unit itself. While each group presented, members of other groups provided feedback via online surveys. After Group 3 had presented, a teacher commented in the online survey, “I think this section should be before group 2.” After the presentation of Group 2, members of Group 3, having read the survey comments they had received, submitted survey comments for Group 2 that showed a taking up of the initial proposal: “It was suggested to group 3 that [group] Q2 and 3 switch order—we think this makes a lot of sense.” Group 3 then brought the proposed switch up for discussion with all the participants present at the meeting, saying “we think that it makes a lot of sense because we’re starting at a very basic level -- trees need
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sunlight, nutrients, and, but they’ve already done the carbon cycle.” A teacher from Group 3 continued, “And it would help you guys (points to Group 2) ‘cause then we’ve introduced trees need water and sun, and then it’s an easier, like, ‘oh and this is why.’”

In the sequence of interactions presented above, however, decisions about phenomena were not motivated by questions students might have, as the Storyline was intended to support. Rather, the sequence was ordered according to teachers’ hypotheses about what concepts would build on one another or be necessary for subsequent lessons. In this respect, teachers’ uptake of the notion of coherence was not as the researchers predicted.

Furthermore, only some of the groups took up these ideas as resources for determining the content of their section of the unit. For example, although Group 2 had received feedback from other groups around the need to revise their lessons so that they more coherently connected back to the anchoring phenomenon and allowed students more opportunities to “figure out” phenomena, some of their final lessons still did not fully reflect these design ideals. One lesson, in particular, stood out as having students simply “learn about” phenomena. Instead of having students explore an observable sub-question that clearly related to the engineering design challenge or anchoring phenomenon by engaging with science and engineering practice, students completed a reading to answer a teacher-supplied question “Where does the mass of trees come from?”

This section demonstrates how teachers engaged with ideational tools during our design process and exercised agency in leveraging them within the design process. While we saw uptake of the distinction between “trust me science” and “figuring out science,” and the virtue of “coherence” in curriculum design, the appropriation of these ideas was uneven across the teachers and groups. That we saw demonstrations of partial appropriation occur within the
context of participants closely engaging with elements of our design process suggests our design approach may continually elicit these ideational tools. Despite only partially appropriating the ideational tools, teachers nonetheless exercised agency in their use, which resulted in lasting changes to the unit and its lessons.

**Evidence of Agency in Reshaping the Design Process**

Teachers not only selected the content of the units, they also appropriated, to different degrees, key ideas from the researchers, and proposed changes to the design processes that challenged how we, the researchers, had organized that process. As described below, the teachers, working in small groups, exercised agency in ways that led to the development of new in-between tools to support more effective design; teachers, working in small groups, utilized critique routines to provide critical feedback on the variability of groups’ progress on generating lesson materials, which prompted changes in group structures; and teachers, through surveys embedded in critique routines, provided feedback that led us to shift the structure of co-design sessions to accommodate their critiques of the process.

**Development of new tools to support the design process.** Teachers working in small groups developed alternative means for designing lessons, in response to perceived limitations in the tools we had provided them. Although the *Storyline* tool proved to have a constant presence throughout the entirety of the design process, shifting in form as deemed appropriate by participants, its ubiquity did not always translate into utility. Below we provide evidence for how teachers, within their small groups, demonstrated transformative agency in their creation of in-between tools that served to alter their own design activity.

In introducing the *Storyline* tool at the 5-day design workshop, the facilitators had intended to support a deeper understanding of the notion of coherence, and provide participants
with a common tool for organizing the creation of a more coherent unit anchored around explaining an overarching phenomenon through the exploration of related sub-phenomena. At this high level of granularity, the Storyline tool served well as a means for coordinating high-level elements of the unit in relation to one another. Issues began to arise, however, during small group work where teachers and their group facilitators had the task of developing actual lesson materials for rows of the Storyline tool, as illustrated by an examination of work that occurred within Group 4.

Participants in Group 4 sought to develop an “in-between” tool to bridge the gap between the Storyline tool and a lesson plan template developed by district administrators and researchers. They desired a tool that better articulated pacing and lesson length. Within their small group, members of Group 4 had criticized the Storyline tool as providing too little support in determining much needed information such as whether all the elements listed in a row would actually fit in their allotted time. In response, members of Group 4 developed an in-between tool to re-represent the information in their row of the Storyline in a format more familiar to teachers and closer to the final format of actual lesson materials, a simple table that described the topics of each lesson and prescribed the number of days each lesson would encompass. Group 4’s envisioning and development of this in-between tool enabled them to engage in more consequential design work. For example, from their in-between tool the participants now had a clearer sense of the purpose and flow of each lesson, their implementation time, and topics each lesson would require or the density of each lesson. This allowed members of Group 4 to divide up coherent sets of lessons among group members in an equitable manner and provided much-desired concrete boundaries for each lesson writer to work within.
Following a previously seen pattern of participants’ agentic acts interlocking and building on one another, this section provides an example of teachers exercising agency to develop a tool that altered their own design activity. Specifically, in taking a neutral, “skeletal” artifact—a table—and filling it with meaning, Group 4 provided a classical example of agency through the method of “double stimulation.” They took up and completed the second stimuli of the table in order to address the immediate problem or first stimulus of creating lesson materials, resulting in an enhanced capacity to pursue the design and development of lesson materials.

**Teacher criticism of variability in groups’ productivity.** In a series of actions that likely reflected a growing sense of ownership over the design process, teacher participants exercised transformative forms of agency almost exclusively through the critique routines provided as part of our design process that led to changes in the participant structure of a small group. We provide evidence below for how teachers exercised agency in contributing to this significant change in the design process.

Although three of the four groups that formed during the conclusion of the 5-day design workshop developed and executed effective plans for going about the work of developing their lesson materials over the following months, one group—Group 2—experienced less success and productivity in developing their lesson materials. In contrast to the other three groups, Group 2 did not complete a team charter, which would have required them to negotiate a strategy for achieving the task of developing tangible lesson materials in the months following the workshop. Instead, the lead facilitator for the group, Mary (a pseudonym), took on the writing of lesson plans herself. A teacher within the group later lamented, “I left the summer with the understanding that Mary wanted to take on all of the lesson writing for our group, so I didn't do any work over the summer. I wish now that I had.” After a face to face meeting wherein Group 2
presented only sparse materials in comparison to other groups, the members of other groups provided feedback to researchers and administrators expressing their displeasure with Group 2’s lack of progress. For example, one teacher offered through a survey, “Those who aren't getting their work done clearly don't value the project, nor the other people who are counting on them.” Other teachers proved more vociferous in their criticisms of Group 2 with one teacher commenting through a survey, “Why is it that we have a group that came to the table more than once without any project complete? We all joined this group knowing what needed to be done, and what we had to do. Group 2 had come to the table MORE THAN ONCE with NOTHING!!![...] The fact that their last presentation of what they have is simply lessons that they have borrowed from someone else is disgusting. It has created a [sic] understory of resentment and discontent.”

The lack of progress displayed by Group 2 prompted interventions from the researchers and district leaders. We added two additional teachers to Group 2 to buoy their ranks. Even then, they still ran into challenges self-organizing productively. For example, in responding to a survey prompt of what concerns she has, one of the new teachers who had joined Group 2 two months prior reported “We are just behind so all of my concerns have been addressed we just need to get some work done. We are meeting next Saturday so we should feel caught up by then.” With hard deadlines for submitting an initial draft of the unit to external reviewers fast approaching, researchers and district administrators decided to bring in an additional facilitator for Group 2 to support the lead facilitator in organizing and executing their work. This decision paid off, as Group 2’s productivity recovered and they delivered tangible lesson materials for the review.
In this section, we sought to demonstrate how teachers utilized elements of our design process, chiefly critique routines, to precipitate a change in the structure of a small group. While the manner in which participants’ agency culminated in these changes followed an interlocking pattern of agentic acts, this example provides a slightly different flavor in that while teachers first exercised agency using elements of the design process, the researchers and administrators ultimately exercised their own agency in carrying out the change to the small group. The fact that the researchers and administrators ultimately held and exercised the agency that resulted in a change in the design process raises questions about the degree to which divisions of labor in our design approach may constrain the agency of teachers.

Recommending shifts in the structure of collaborative design sessions. The most significant changes to the design process brought about by teachers’ exercising transformative forms of agency dealt with shifts to the structure of the collaborative design sessions. In this section, we provide evidence for how teachers exercised agency that led to fundamental shifts in the structure of joint co-design sessions. Teachers provided, but also went beyond criticism to make concrete proposals for organizing the co-design process to be more productive and satisfying to them. Their proposals, as we elaborate below, called for more collaborative, face-to-face work among the teachers so that they could engage more deeply with the ideas they were discussing, and rely more on one another to develop lessons.

After the intensive 5-day design workshop held during the summer, the structure of whole-group design work shifted to other formats during the late summer and into the school year, which some teachers criticized and sought to change. Teachers expressed concerns over the structure and effectiveness of regular, hour-long videoconference meetings that all participants had attended to discuss their progress. Teachers suggested that the videoconference meetings did
not provide the depth of interaction they had experienced in face-to-face meetings. For example, one teacher commented in a survey, “I dont [sic] see the Zoom [videoconferencing software] calls as helpful as the face to face meetings.” Similarly, another teacher offered “I think face to face meetings are key - it is tough to work virtually. I have found that quality of the work we produce after face to face meetings is much greater than after virtual work.” Teachers cited the lack of “big blocks of time together” as a key limitation of work format during the school year, with one teacher even suggesting that the format of “stretching this 1 unit out into meeting, after meeting, after meeting, has not been conducive to creating a solid product.”

Going beyond simply offering criticism, several teachers provided very similar potential remedies for addressing the ineffectiveness they either specifically perceived in the work format implemented by researchers and administrators during the school year, or for how to generally improve the design process. Of the eleven teacher participants, six suggested through their survey responses of the need to alter the design process so that participants would engage in more face to face, intensive design sessions occurring over what one teacher envisioned as “continuous blocks of time.” More specifically, four of these six participants suggested that such work should occur exclusively during the summer months. For example, one teacher offered the following: “I propose more similar time like we had in Boulder, short, sweet and intense. I do not think I can commit to this project if the rest is to be completed during the school year. It has actually created resentment (others have said the same to me) toward the project for eating into the little time that we have during the school year.” The suggestion of moving the bulk of design work outside of the school year to the summer serves as a prominent instance of teachers’ agency leading to a substantial shift in the overall design process. Subsequent design work, where teachers engaged in revisions of the ecosystems unit and developed new biology units, made use
of the design format teachers first suggested here, although some design work still had to occur during the school year.

This section described how teachers exercised agency to achieve a new form of activity in the design process, namely a new structure for joint collaborative design sessions. Similar to the instance regarding criticism of Group 2 above, teachers utilized almost exclusively the elements of our design approach, such as the surveys embedded within critique routines, in exercising their agency. However, once again, this example demonstrates an imbalance in agency between teachers on one side and researchers and administrators on the other: the division of labor ultimately placed the agency to make the structural changes suggested by teachers in the hands of researchers and administrators. Additionally, researchers and administrators did not fully implement the suggestions made by teachers.

DISCUSSION

Our paper illustrates one way that CHAT can inform both the organization of a collaborative design process and an analysis of its effects. In terms of O’Neill’s (this issue) first question about what a CHAT perspective buys us, CHAT foregrounded in our design approach the importance of promoting teacher agency as an object of design, and it provided us with a method (double stimulation) for introducing tools and routines that could facilitate the development of curriculum materials to embody an external vision of how to reform science education. It also provided us with a lens for judging the success of our efforts: specifically, whether the agency of teachers proved transformative, and led to new forms of activity (Engeström et al., 2014; Virkkunen, 2006).

By focusing on organizing for agency, we brought to the foreground aspects of the design process that are not always highlighted in accounts of design-based research (Ormel et al., 2012),
except among scholars who theorize the role of co-design in supporting teacher involvement in changing their own instruction (e.g., Voogt et al., 2015). Our description of the co-design process is different from earlier attempts to theorize co-design as a mechanism for promoting teacher learning, however, in that we specified ahead of time how specific tools and routines were intended to serve as a “second stimulus” to support the work of design teams. In doing so, we hoped to hold ourselves to account for our decisions about how to organize the design process, much as some other learning scientists have advocated with respect to innovation designs (e.g., Sandoval, 2014).

Our approach to analysis, moreover, contrasts with earlier empirical analyses presented retrospectively, and mostly in first-person accounts of the co-design process from researchers (e.g., Kwon, Wardrip, & Gomez, 2014), which are subject to retrospective re-organizing of accounts, and from analyses that focus on teachers’ experience of the co-design process (e.g., Penuel et al., 2007) rather than on the actual recorded actions of participants. In addition, in attending carefully to acts of resistance by teachers in the design process as a form of agency (see Engeström et al., 2014), we gained awareness of ways that teachers influenced not only the new curriculum’s content, but also the design process itself. Finally, our detailed analysis of interaction revealed specific examples of how valuable contributions from teachers and other participants did not originate from any one individual, but instead occurred through intricate interlocking agentic processes, of participants taking up and building upon the ideas of others.

As noted at the outset, because we began with an external vision for reforming science teaching and learning, our approach was different from other CHAT-inspired intervention research, which positions implementers as the primary if not sole source of ideas for addressing problems of practice. Our research team, supported by district administrators, provided second
stimuli that were more “ambiguous” than “neutral,” that is, they were directed to realize particular aims for transforming teaching and learning activity in classrooms, even if these tools did not dictate the focal phenomenon of the unit or the content of specific lessons. In this respect, it is our view that CHAT alone was insufficient to guide design; we needed to bring in specific concepts and tools developed as part of other traditions of design-based research in the learning sciences to accomplish our aims. The researchers, moreover, contributed in an ongoing way to the development of lessons, serving as primary authors of more than one third of the lessons in the unit. As such, to answer the question of “Who does the design and why?” (Engeström, 2011, p.600) the “who” is a bit different in our work than the answer for other CHAT intervention research projects. The answer is that “we” do the design, where the “we” encompasses teachers, researchers, curriculum developers, and district administrators.

These differences from CHAT intervention research, as well as the counter-evidence we developed related to teacher agency, underscore to us the ways that our own co-design process was not fully democratic (see also Penuel et al., 2007). The researchers and district leaders held the power for deciding how to structure the design process and for selecting which tools and routines to use as second stimuli in the process. We also were responsible for selecting the teachers who participated in design, and for managing the funds to pay teachers. In addition, by imposing an external vision for reform on the design process, we constrained possibilities for breaking away from current patterns of activity and from the current division of labor between district leaders and teachers. The external object, fortunately, was one that was itself ambiguous and underspecified, leaving room for teachers to design curriculum materials that they believed would engage their students and result in more powerful learning experiences for them.
One reason why we were not fully democratic in our process pertains to the expectations of funders. Funding for our project came to the researchers from the National Science Foundation, and through the process of peer review, our project’s plan to co-design materials was judged to have sufficient intellectual merit and potential for broader impacts to warrant a recommendation for funding. At the same time, this agency, like others, holds the researchers accountable for the outcomes of the project. We took that responsibility seriously, in that we sought to make sure that the designs we created were innovations that built on past research and had potential to be transformative, a key criterion that the funder uses to judge the merit of projects. We therefore maintained decision making power for overall direction of the project, despite our commitments to supporting teacher agency in design. For us, the question of how to preserve latitude with funders who have committed to partly defined goals raised by O’Neill (2016/this issue, Question 2) remains challenging, because whenever funding goes to researchers and not to partnerships that share equally in decision making, it is not possible to implement fully democratic design processes.

CONCLUSION

In this paper, we have described how CHAT informed our organization of a design space in which we sought to promote the agency of teachers as they engaged, via co-design, in the development of curricular materials meant to embody the vision for science education called for in the Framework. CHAT drew our attention to the need to organize the design process and place agency with teachers as a fundamental desired outcome (Engeström, 2011). Specifically, CHAT oriented us to seek to foster forms of transformative agency, defined as a joint effort to envision and bring about new forms of activity, to break away from older patterns of activity (Virkkunen, 2006). As in many other design-based research projects, we intended the objects to be used by
students and teachers in classroom settings. In our project, however, we focused our attention on
the organization of the design space in which participants developed such objects (e.g.,
curricula). We did so because of our interest in promoting transformative forms of agency that
could lead to a new form of activity in curricular design spaces, one that confronts the traditional
division of labor that defines policymakers and researchers as “designers” while positioning
teachers as only the “implementers” of policies, programs, and practices.

We have provided evidence that the collaborative design of materials can be organized to
promote teachers’ agency and enable them to productively leverage their expertise when the
vision for reform is external but not completely specified ahead of time. While seeking to
develop curricular materials embodying an external vision for reforming science education,
teachers in this project enacted agency through engagement with elements of our design process.
When teachers exercised forms of transformative agency, they significantly shaped both the
content of new curriculum materials and the design process itself. Our study has further
illustrated how substantial contributions can come about from participants building on the
contributions of others in collective design activity. In several cases, these contributions were
creative and innovative. Together, we also figured out—partly through trying different second
stimuli—better and more varied means to support the development of coherent curriculum
materials by listening to and responding to teachers’ concerns about the design process.

When researchers bring to the design process an external vision for improving teaching
and learning, the kinds of theories of disciplinary learning and pedagogical design that design
researchers in the learning sciences have developed in the past can suggest what might be
appropriate “second stimuli” in design. Such tools may be useful to teams, when presented as
“principled practical knowledge” (Bereiter, 2014) derived from past research. As Engeström
(2011) reminds us, however, it is important to take care that the external visions presented to participants as second stimuli do not become mechanisms of control for and by researchers in design research. Just because something worked “elsewhere, elsewhen” does not mean that it will work in a new context.

Our own experience and analysis in the Inquiry Hub has led us to as many questions as answers with respect to how to promote meaningful teacher agency in design. Although our results provide evidence of the power of purposefully promoting teacher’s agency to leverage their expertise in design, several aspects of our curricular materials and changes to our design process relied heavily on the agency of researchers and administrators in order to become enacted. Navigating how to plan for more democratic forms of participation within our research-practice partnership will continue to serve as a focus of future work. In addition, whether or not the vision of A Framework for K-12 Science Education (National Research Council, 2012) can be realized without expanding teachers’ agency in significant ways is still an open question, though we are persuaded by past research that suggests teacher agency is critical for realizing that vision.

More broadly, we see the need for theories of design methodology in the learning sciences to structure collaborative design in ways that simultaneously promote the agency of participants within the design process, and expand possibilities for what new forms of activity are possible in classrooms. As we have argued here, CHAT provides an important lens for helping us to design for and analyze agency.
CHAPTER III

ARTICLE 2

Relevant Learning and Student Agency within a Citizen Science Design Challenge

by

Samuel Severance

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ABSTRACT

This study examines the implementation of a biology unit organized around a citizen science design challenge and designed to align to the Next Generation Science Standards (NGSS; NGSS Lead States, 2013). This study utilized a mixed methods approach, including quantitative analysis of survey responses from students across eight classrooms piloting the biology unit, and ethnographic qualitative methodologies to discern the experiences of students within two specific teachers’ classrooms. This study explored whether the unit promoted relevant learning experiences for students and whether students felt a sense of agency when engaging in the use of science and engineering practices. Results indicate that (1) students saw their learning and activity in the unit as more relevant to their community than themselves; (2) students felt a sense of agency in the unit, particularly while engaging in the science and engineering practices of planning and carrying out investigations and obtaining, evaluating, and communicating information; and (3) students saw greater relevance of the curriculum to themselves and their
classroom and felt a greater sense of agency when they saw a connection of the lesson to the overall challenge for the unit.

**RELEVANT LEARNING AND STUDENT AGENCY WITHIN A CITIZEN SCIENCE DESIGN CHALLENGE**

Traditional forms of science education often deny students the opportunity to experience learning they find relevant and meaningful and that allows them to exercise agency in their learning by applying what they have learned towards problems they see as important and consequential. Instead, students often experience less meaningful forms of science learning, doing isolated activities lacking connections to the world outside of the four walls of the science classroom and lacking opportunities for exercising meaningful agency in their learning (Engeström, 1991). Breaking this pattern of schooling seen in traditional forms of science education requires shifting instruction to purposefully position students in more agentic roles, where they can apply their learning to accomplish something of worth with meaning to themselves and their communities (Lee & Roth, 2003). In essence, science education should seek to empower students “to act (not merely to know)” (Eisenhart, Finkel, & Marion, 1996, p.282).

The bold re-envisioning of what should constitute science learning within the *Framework for K-12 Science Education* (*Framework*; National Research Council, 2012), as carried forward in the Next Generation Science Standards (NGSS; NGSS Lead States, 2013), supports calls for making students’ learning more relevant and for positioning students in more agentic roles. The *Framework*, for example, calls for instruction that purposefully attends to issues of relevance, primarily through seeking to create meaningful connections between the classroom and students’ experiences outside of the classroom. It calls for more agentic roles in science classrooms, wherein students have the opportunity to deeply engage in science and engineering practices to
develop understandings of core ideas and crosscutting concepts, or what the Framework refers to as “three dimensional” science learning (National Research Council, 2012). Adoption of the NGSS by states and districts also holds the promise of promoting more equitable opportunities for all students to experience more meaningful science education.

In this study, I propose that a citizen science project integrated into a formal biology school curriculum has the potential to support the realization of the vision for science education put forth in the Framework. While citizen science projects offer students opportunities to develop meaningful agency and encourage students to see their learning as relevant as they productively utilize their learning towards authentic and meaningful ends (Roth & Lee, 2004), few quality citizen science projects have been integrated into curriculum. This represents a lost opportunity to promote more equitable access to meaningful science learning for all students. How to effectively implement a citizen science curriculum within formal school settings that promotes students’ sense of agency and supports students in seeing their learning as relevant and meaningful remains a largely unexplored space. In addition, the potential benefits to students and communities of such a curricular approach also remain largely unexplored.

Taking place within the formal setting of a large, urban school district, this study examined the implementation of a biology unit on ecosystems organized around a citizen science design challenge and designed to align to the vision of the Framework and the NGSS. This study sought to understand whether and how various teachers’ enactments of the unit supported their students in experiencing more meaningful forms of science learning. Specifically, this study sought to understand whether and how students came to perceive their learning in a unit with a citizen science component as relevant and whether and how students came to experience a sense of agency within the context using of science and engineering practices as called for in the
Framework and NGSS. As such, this study explored the following questions:

1. **Agency in Science and Engineering Practices**: What agency did students have in using science and engineering practices to figure things out in class?

2. **Relevance**: How relevant did students perceive their activity in the unit to be to themselves, their classmates, and to their communities?

3. **Citizen Science Challenge as Promoting Relevance and Agency**: How did the overall citizen science design challenge figure in students’ perceptions of relevance and their sense of agency?

**CONTEXT FOR THE STUDY**

Previous research points to a number of considerations for science curriculum seeking to make learning more relevant to students and provide opportunities for students to exercise agency in science classrooms. For one, curriculum should “connect to the interests and experiences” of students, so they can see it as pertinent to their own lives (National Research Council, 2012, p. 28). Second, students need to have opportunities to have both control within and take responsibility for their own learning; curriculum materials should provide them with opportunities to apply science ideas while using science and engineering practices in meaningful contexts.

**Need for Relevance in Science Education**

The Framework demands that curriculum materials demonstrate relevance (National Research Council, 2012), defined in this study as the property of meaningfulness or importance attributed to an object or experience. Curriculum materials should seek to capitalize on students’ interests and experiences to foster a sustained attraction to science and an appreciation of the many ways in which science is pertinent to their daily lives (National Research Council, 2012).
Curriculum materials should focus on identifying phenomena that intersect with the experiences and knowledge that students bring to school and that spur rich questions that students might actually pose, questions that can serve to organize the structure of materials and motivate students in the exploration of a phenomenon.

Promoting a sense of relevance on the part of students can occur by attending to different forms of relevance. Polman (2012) proposes a framework for more effectively engaging students in disciplinary practices that includes attending to different “senses of authenticity” (p.226). This study adapts this framework by identifying how each form of authenticity relates to a distinct form of relevance. The forms of authenticity put forth by Polman (2012) include *externally authentic cultural tools*, which indexes the relevance of disciplinary tools used in learning activities to their use in disciplinary communities; *authentic community connections*, which indexes the relevance of performing activities that have meaning and importance in the wider community; and *authentic personal agency*, which indexes the relevance of an activity for individuals engaged in the activity.

**Need for Agency in Science Education**

Studies of agency in science education and agentic forms of science literacy as well as the *Framework* call for attending to agency, defined in this study broadly as the capacity to have control over one’s activity and produce a desired change, in order to achieve more meaningful forms of science learning. Eisenhart and colleagues (1996) conceptualize an agentive form of science literacy where students become empowered “to act (not merely to know)” (p.282), and demonstrated the effectiveness of such an orientation in supporting groups to develop community-oriented “alternate means” (Eisenhart et al., 1996, p. 283) to learn science. Similar orientations of supporting students’ agency and empowering students comes from Roth and Lee
A call for agency in science education also comes from the Framework. Specifically, the Framework identifies principles that promote agency while engaging in discussions of equity. The Framework calls for equipping all students with the means for meaningfully engaging in issues pertinent to themselves and their communities (National Research Council, 2012, p.278), essentially seeking to increase students’ agency in terms of increasing their capacity to have a meaningful effect on something in their lives. Ensuring science instruction provides opportunities for students to appropriate the tools necessary for affecting their own lives and those in their community requires purposefully attending to issues of inclusion and motivation. The Framework suggests some directions for increasing inclusion and motivation such as providing roles that allow students to identify as scientists, leveraging local community ways of knowing, and engaging students in challenges (National Research Council, 2012).

**Approach of Engaging Students in Science and Engineering Practices**

In terms of how to promote more meaningful science learning, the Framework calls for students to engage with science and engineering practices to support “three-dimensional science learning” (National Research Council, 2012, 2014a), wherein students engage in science and engineering practices to build pieces of disciplinary core ideas and make connections to crosscutting concepts while investigating phenomena or designing solutions to problems. Engagement in science practices promotes productive disciplinary engagement, where students use of scientific practices reflects the use of scientific practices by professionals and leads students to experience intellectual progress over time (Engle & Conant, 2002). In other words, the use of science and engineering practices can support students to actively “figure out” their
learning around scientific phenomena much as scientists do rather than simply “learn about” them in a passive manner from another authority, such as their teacher (Reiser, 2014). As such, engagement in science and engineering practices can support students’ sense of agency, particularly through positioning students in more agentic roles in the classroom (Herrenkohl & Guerra, 1998; Varelas, Tucker-Raymond, & Richards, 2015) and by leading students to have more authority or control over their own learning (Engle & Conant, 2002; Cornelius & Herrenkohl, 2004).

**Approach of Citizen Science**

In addition to having students engage in science and engineering practices as part of three-dimensional science learning, the use of citizen science, where the public participates in organized research efforts (Dickinson & Bonney, 2012), can also support the twin goals of relevance and agency. Citizen science efforts can take many different forms from research on cataloging stars, to testing water quality, to surveying local biodiversity, etc. In terms of promoting more relevant learning, citizen science is typically organized around an ongoing science project tied to a professional organization, university, or government agency, that centers on answering questions posed in the professional scientific community or addresses consequential problems *from outside of the classroom* that participants can engage within their own communities. Participants in citizen science projects have the opportunity to actually contribute to these efforts, typically by collecting and submitting data (Trautman, Shirk, Fee, & Krasny, 2012).

In terms of supporting students in developing a sense of agency, citizen science allows for students to wield science *in practice* (Penuel, 2014b), that is, in action while actually contributing a meaningful service to their community. Contrasting with traditional forms of
science education or project-based learning, citizen science provides opportunities to experience agency that has the potential to lead to impacts outside of the classroom, where students have the actual chance “to act (not merely to know)” (Eisenhart et al., 1996, p.282). In addition, while engaging in the central problem or question of a citizen science project, participants investigate these problems or questions through scientific practices (Trautman, et al., 2012), which can position students in agentic roles where they have the opportunity to have authority over the process of figuring out a problem or phenomena.

Citizen science projects, however, face challenges in terms of their implementation in formal school settings. While integrating a citizen science project into formal school settings could support educators with the means to support students in seeing their learning as relevant and develop their sense of agency, citizen science projects rarely offer curricular supports, such as tools to help teachers and students move beyond mere data collection (Trautman et al., 2012). All too often, citizen scientists only have the opportunity to collect data, a situation that seems less like citizen science than “using citizens to do science” (Lakshminarayanan, 2007). Most projects do not have students define questions or methods of data collection, which limits the scope of their engagement in science and engineering practices. Even some of the most well-known citizen science projects, such as those organized by the Cornell Lab of Ornithology, offer no opportunities for participants to engage in deeper science practices beyond collecting data while carrying out someone else’s investigation (Bonney et al., 2009; Evans et al., 2005). Efforts to treat citizens as scientists on equal terms need to occur (Lakshminarayanan, 2007). Providing students with more authority to take up more science and engineering practices in contributing to citizen science projects will better support students in understanding how scientists actually produce scientific knowledge.
CONCEPTUAL FRAMEWORK

Sociocultural Theory and Cultural-Historical Activity Theory

This study utilized sociocultural theory as its overarching conceptual framework, specifically aspects of third-generation Cultural-Historical Activity Theory (CHAT; Engeström, 2001). Given how, in the words of the Framework, “[a]ll science learning can be understood as a cultural accomplishment” (National Research Council, 2012, p. 283), and this study’s interest in both understanding how to promote agency in students’ science literacy—considered here a social achievement (Eisenhart et al., 1996; Roth & Lee, 2004; Scribner, 1984)—as well as understand how to promote a sense of relevance in regards to the curriculum, sociocultural theory as realized through CHAT provided an appropriate means to frame the analysis for this study. CHAT provided productive frames to understand how various students experienced the implementation of the ecosystems unit, specifically, how students may have come to perceive the unit as having meaningful relevance and how the unit may have promoted a sense of agency, as well as how students took up science and engineering practices to address the citizen science project.

Relevance from Sociocultural and CHAT Perspective

Sociocultural theory and CHAT provide some insights as to how students may come to see their learning as relevant while engaging with science curricula. CHAT posits that individuals orient their activity within a collective activity system, like a classroom, towards a shared object or goal (Engeström & Sannino, 2010b). Typically, in expansive learning cycles, the object results from negotiation amongst members of an activity system, preserving and fostering agency in having the voices of participants be heard in defining a problem they find personally relevant to their activity (Engeström & Sannino, 2010b). Providing students with the
object of a curriculum runs the risk of students not viewing the provided object as relevant to their lives and communities, leading to disengagement with the curriculum. To increase the odds of having students see the object of their activity as meaningfully relevant requires carefully choosing a suitable object, one that provides relevance and that preserves, as much as possible, the agency of students. The developers of the unit looked to citizen science in selecting the object of the unit feeling it offered the greatest possibility of meeting both of these aims.

Instead of using an object originating and ending within an encapsulated classroom (Engeström, 1991), citizen science purposefully expands the activity system of learners into the community to take advantage of pre-existing objects. Ideally, a properly chosen object for a citizen science project will already have relevance for students in addition to having qualities that promote the meaningful use of agency. Additionally, expanding the activity system through citizen science creates a hybrid space between school and community and potentially allows for students to have access to more mediational means, such as students’ interests and experiences (National Research Council, 2012). This can allow for students to utilize these resources developed outside of school, or “funds of knowledge” (Moll, 1998), as mediational means towards addressing the provided object, creating more opportunities for students to make relevant connections to the object. The use of a citizen science challenge provides a purposefully incomplete object that requires students to engage with tools or practices to complete the challenge. As students engage with these tools or practices towards achieving the object, they appropriate these tools and practices and come to see them, and their activity more generally, as relevant as they imbue them with their own intentions (Wertsch & Rupert, 1993).

Agency from Sociocultural and CHAT Perspective
Sociocultural theory and CHAT also provide insights into how students may come to experience agency while engaging with science curricula. Agency, defined here broadly as the capacity to have control over one’s activity and produce a desired change, is considered both an important outcome and mediator in this study. Vygotsky addresses the mechanism of agency most directly when talking about cultural mediation, the use of cultural tools as an “auxiliary means” (1978, p.52) for brokering individuals’ actions and experiences in the world.

The person, using the power of things or stimuli, controls his own behavior through them, grouping them, putting them together, sorting them. In other words, the great uniqueness of the will consists of man having no power over his own behavior other than the power that things have over his behavior. But man subjects to himself the power of things over behavior, makes them serve his own purposes and controls that power as he wants. He changes the environment with the external activity and in this way affects his own behavior, subjecting it to his own authority. (Vygotsky, 1997, p. 212)

In Vygotsky’s view, the degree to which an individual has the capacity to have control or authority over their own activity and behavior and produce a desired change or effect in their environment relies on their capacity to take up and apply cultural tools or practices. This implies that just giving children opportunities to explore open-endedly is not sufficient to promote meaningful agency. Students will need cultural tools to support answering their own questions and designing their own solutions to problems.

Vygotsky’s views on agency also emphasize the role of volition, or choice, in whether and how an individual takes up a tool and uses it as mediational means in producing a change (Vygotsky, 1978, p.74). Within science curriculum, this pertains to the opportunities a student may have to take up tools and practices, notably science and engineering practices, in order to
SUPPORTS FOR IMPLEMENTATION OF NGSS

carry out and complete tasks. As students ideally “develop both the facility and the inclination to call on these practices, separately or in combination, as needed” (National Research Council, 2012, p. 49), they must exercise agency in terms of their own volition in determining when and how to make use of certain science and engineering practices. Sociocultural theory also provides some insights as to the importance of keeping science and engineering practices focal within instruction to promote agency, in terms of authority. As students engage and develop a “grasp” of science practices, they gain disciplinary authority which they can leverage during the social and collective activity occurring within the science classroom (Ford & Forman, 2006). Having authority in the science classroom can allow for students to have more opportunities to “figure out” science phenomena or challenges on their own, leading to a sense of agency.

THE CURRENT STUDY

This study is an implementation study examining how students experience a citizen science project that serves as the spine of a curricular unit. Given this study’s emphasis on understanding the experience of teachers and students, this study employed ethnographic qualitative methodology as its primary means of data collection and analysis. Ethnographic qualitative methodology provides an effective means of capturing individuals’ activity in a setting over time, primarily through field notes, in order to construct a “thematic narrative” (Emerson, Fretz, & Shaw, 1995b, p. 170) of participants’ experiences. Developing narratives of teacher and students’ experiences allows researchers to discern both patterns of engagement common across participants and identify instances where participants’ experiences significantly differed. To attain a broader sense of students’ experiences during the implementation of the unit, this study also employed quantitative analysis of survey responses from students across all
participating classrooms. Such analyses can provide broader patterns of evidence and also serve to contextualize evidence gleaned from ethnographic qualitative methodology.

**Participants in the Study**

This study took place within a large, urban, school district in the western United States. The district in question belongs to a long-term RPP called the Inquiry Hub (iHub), which has supported the district in designing innovative curricular materials informed by research and implementing them in district classrooms. Over the past few years, the district has moved towards adoption of the NGSS, this despite the state in which the district resides having not adopted the NGSS. Given the dearth of available curriculum materials aligned to the Framework (National Research Council, 2012; Roseman et al., 2015), the iHub sought to develop novel curriculum materials aligned to the Framework and NGSS. Through a continuing co-design process (Severance, Penuel, Sumner, & Leary, 2016; Voogt et al., 2015)—involving science teachers from around the district, district administrators, curriculum designers, community members, and researchers—the iHub developed a portion of a high school biology curriculum, specifically, an eight-week unit on ecosystems.

**General participants.** This study examines the implementation of the ecosystems unit in the classrooms of twelve teachers. Teachers self-selected into the study after iHub members performed a district-wide recruitment process. The twelve teacher participants, with teaching experience ranging from 2 years to 20+ years, represented eight separate schools from across the district. The implementation of the unit occurred within thirty-six biology sections. Approximately 975 to 1000 students experienced the ecosystems unit. In the year of this study, Hispanic students comprised approximately 56% of all students in the district, Black students comprised approximately 14% of all students, and 69% of students in the district participated in
the free or reduced price lunch program. Actual student demographics within each school, however, could vary from these averages in terms of race or ethnicity and socioeconomic status.

**Selection of focus participants.** Two teachers in the pilot from different schools volunteered to serve as focus teachers and have their classrooms serve as focus classrooms for this study. As such, these two classrooms underwent more focused data collection by researchers, including regular classroom observations, interviews with the focus teachers, and the collection of artifacts created by students. In addition to the willingness of these two teachers to have their classrooms serve as focus classrooms, selection of these classrooms centered on the student demographic makeup of these teachers’ schools. These focus teachers’ classrooms allowed researchers the opportunity to observe and compare the implementation of the unit with different student body demographics, which researchers surmised could provide important insights in terms of how students engaged with the unit. One classroom teacher, Clarissa, resided at the Beacon Community School (a pseudonym), where approximately 92% of students identified as Hispanic, 5% identified as Black, and 99% of all students participated in the free or reduced price lunch program. The other classroom teacher, Beth, resided at the Creative Arts Academy (a pseudonym), where 15% of students identified as Hispanic, 5% identified as Black, and 12% of all students participated in the free or reduced price lunch program.

Three students from each focus classroom served as focus students. Researchers selected these students at the outset of the implementation of the unit in consultation with the focus teachers. Serving as a focus student involved participating in interviews at regular intervals during the unit. Students who expressed interest in serving as focus students underwent additional assent and consent procedures. A fraction of students returned these forms in a timely manner prior to the first scheduled interview. Four students who had shown consistent
attendance and assignment completion, as judged by the focus teachers, became focus students for this study. One Hispanic male and one Hispanic female served as focus participants from Clarissa’s class. One Asian female and one white male served as focus students in Beth’s class. Of note, researchers did not have IRB permission to access students’ personnel files to determine if students had received certain designations indicating an outlier status, such as gifted and talented or participating in special education.

The Curricular Intervention: iHub Ecosystems Unit

To achieve the Framework’s vision for science education as embodied in the NGSS (NGSS Lead States, 2013), curriculum will play an integral role (National Research Council, 2012). This study examines the implementation and effect of a curriculum developed through a co-design process involving teachers, district administrators, curriculum developers, researchers, and community members from a local parks and recreation agency and environmental non-profits. This unit, the first of four planned for implementation, has the ultimate goal of increasing students’ science literacy (Eisenhart et al., 1996; Roth & Lee, 2004), both in terms of developing agency and in terms of developing students’ use of meaningful three-dimensional science learning around the disciplinary core idea “HS-LS2 Ecosystems: Interactions, Energy, and Dynamics” (NGSS Lead States, 2013). To achieve this goal, the designers of the unit sought to meet key demands called for in the Framework: (1) curriculum should provide students with a sense of coherence so that students build understanding over time, (2) curriculum materials should demonstrate relevance to students’ interests and experiences, and (3) curriculum materials should have students engage with science and engineering practices as part of three-dimensional science learning.
How the unit promotes relevance and agency. To promote relevance to students’ interests and experiences, the unit departs slightly from Reiser’s (2014) recommendations. Instead of a unit driving question, the ecosystems unit poses an engineering design challenge to the students. This challenge, given to the students by the local parks and recreation department, provides an authentic science context and equitable citizen science arrangement for students. The citizen science design challenge calls for students to determine which tree they could plant in their local ecosystem in order to help maintain the services their urban ecosystem provides. Students address the challenge by engaging in science and engineering practices both within the classroom and in the community, utilizing specially designed tools. These tools, such as a digital tool called EcoSurvey used to support students in surveying the biodiversity of their ecosystem, allow for students to complete them and imbue them with their own meaning, fostering students’ agency while they pursue the challenge. Eventually, students must provide the parks and recreation department with a solution to the challenge, an evidence-based recommendation of which tree they should plant and where. The unit culminates with the parks and recreation department supplying students with their chosen trees and assisting with their planting, allowing students to achieve the object of their collective efforts and realize it as a meaningful outcome in their community.

How the unit engages students in science and engineering practices. The use of science and engineering practices has an essential role within the unit, providing a means to promote both coherence and facilitating the development of students’ sense of agency in trying to “figure out” (Reiser, 2014) a relevant object, the challenge. As mentioned, students engage in science and engineering practices as a means to explore phenomena within the unit and simultaneously build pieces of disciplinary core ideas and connections to crosscutting concepts.
as envisioned in three-dimensional science learning. The unit purposefully arranges students’ pursuit of the challenge and its associated phenomena within social interactions, having students, for example, engage in argumentation of evidence, offer explanations of phenomena, and communicate information. In doing so, students gain access to the expertise of their peers and facilitate the internalization of shared meanings. As students move through the unit, they must continually take on more of the responsibility of how to productively engage with science and engineering practices. These efforts culminate in the development of their solution to the challenge where students have the most agency in determining how to utilize the practices. In this manner, the students develop an agentive form of science literacy, a “social achievement” (Scribner, 1984, p. 7), with which they can collectively exercise to productively manage their local urban ecosystem.

**Data Collection and Procedures**

Researchers collected data from five sources during the implementation of the ecosystems unit: (1) student online surveys, (2) field notes of classroom observations, (3) focus student interviews, (4) focus teacher interviews, and (5) student created artifacts. Table 1 summarizes these sources of data and their correspondence to research questions.
Table 1

Sources of data and alignment to research questions

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<th>RQ 3 (Citizen Science)</th>
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<td>X</td>
<td>4 interviews</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Transcripts (4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Audio (4)</td>
</tr>
<tr>
<td>Student Created Artifacts</td>
<td>X</td>
<td></td>
<td></td>
<td>70+ items</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Digital (50+)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Physical (20+)</td>
</tr>
</tbody>
</table>

**Student online surveys.** Students from across all classrooms completed surveys online during class, typically on a weekly basis. Teachers typically had students complete these surveys at the end of class using laptop computers. The surveys served as a practical measure (Bryk, Gomez, Grunow, & LeMahieu, 2015) of implementation. Practical measures allow researchers to quickly gauge the effectiveness of a design (Yeager, Bryk, Muhich, Hausman, & Morales, 2013). See Appendix B for the Fall 2015 practical measures questions. For each lesson, these items provided data on students’ affective responses, whether or not they felt their learning connected to the challenge (RQ 3), their perception of the relevance of their activity to themselves and others (RQ 2), and the degree to which they felt they figured out aspects of the day’s lesson (RQ1). From a previous implementation of the unit, some evidence of predictive validity for some items exists, chiefly that students feel more interest and enjoyment when they engage in...
activities that build toward the challenge. Students submitted 1224 responses and the survey system would only accept responses that had completed all items on the survey.

**Observations of unit implementation.** I performed observations of the implementation of the unit on a weekly basis in the two different focus teachers’ classrooms. Data collection focused on how students and teachers implemented components of the ecosystems unit, with a particular emphasis on any adaptations made to the unit, the use of science and engineering practices (RQ 1), whether students or teachers marked the importance of an aspect of the unit (RQ 2), and how students engaged with the challenge (RQ 3). Although the majority of these observations took place within the confines of pilot teachers’ classrooms, the unit required students to engage in activity outside the classroom on school grounds and the surrounding community. I observed focus students and their groups as they carried out these investigations, using a participant observer role (Spradley, 1980). I created fieldnotes from classroom observations. In addition, I made digital audio recordings of nearly all classroom observations and referenced portions of audio recordings to check for the accuracy of fieldnotes.

**Focus student interviews.** Each of the focus students participated in three semi-structured interviews. The first interview occurred at the outset of the implementation of the unit, the second occurred approximately in the middle of the unit, and the last interview occurred at the conclusion of the unit. I made audio recordings of all interviews and created verbatim transcriptions from these recordings. The interviews sought to gauge how students’ experienced the unit over time and what features of the unit’s implementation most influenced students’ experiences. See Appendix B for the interview protocol for students in Fall 2015. Each interview started with general questions about the unit, for example, what they thought the unit was about and what students have done thus far in the unit (RQ 3), and how useful they think what they
have learned is (RQ 1). Following these general questions, researchers asked students specific questions about their experiences, such as when during the unit did students feel like they figured something out (RQ 1), and how relevant they felt the unit was in relation to themselves and others (RQ 2).

**Focus pilot teacher interviews.** I conducted two semi-structured interviews with the two focus pilot teachers. I captured all interviews using audio recorders and transcribed these recordings verbatim. See Appendix B for the focus teacher interview protocol for Fall 2015. The first interview occurred at the outset of the unit and sought to better understand the teachers’ current school contexts, how they went about teaching (e.g. resources referenced, when and how they adapt tools/materials), and beliefs about how students learn (RQ 1, RQ 2), as well as their students’ experiences of the unit thus far (RQ 3). The second interview occurred after the implementation of the ecosystems unit and asked teachers to reflect on the effectiveness of the unit (RQ 3), adaptations they made to the unit (RQ 3). In addition, researchers re-administered previous questions on teaching practices and beliefs (RQ 1, RQ 2).

**Student created artifacts.** Throughout the eight-week unit, students created physical and digital artifacts during activity related to the unit. The creation of many of these artifacts required the use science and engineering practices and the building of disciplinary core ideas (RQ 1). As such, artifacts provided instances of students engaging with science and engineering practices in the context of the ecosystems unit.

**Methods of Analysis**

I employed a mix of quantitative and qualitative techniques for this study to discern patterns of evidence that could lead to potential claims attending to this study’s research questions (see Table 2). The use of a mixed-methods approach to analysis provided me with a
robust means of examining potential patterns of evidence across a variety of data sources to create accounts of teachers’ and students’ experiences in the unit. In this study, I used quantitative analyses primarily to identify potential associations between variables relevant to this study’s research questions across all classrooms and identify potential differences between classrooms (see Table 2). Qualitative analysis focused strictly on data from select classrooms to better understand how these variables may have actually influenced the experiences of participants (see Table 2).

Table 2

Relevant variables and types of analyses

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Quantitative Analyses</th>
<th>Qualitative Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>RQ 1 - Agency and Science &amp; Engineering Practices</td>
<td>Student Online Survey Data Means, SDs of responses overall and by classroom for item “How I learned today”</td>
<td>Classroom Observations, Student Interviews Code co-occurrence of choice or control, effect of actions, science and engineering practices and interpretation of excerpts</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td>RQ 2 - Relevance to Self, Class or School, and Community</td>
<td>Student Online Survey Data Proportion of responses (%) overall and by classroom for item “Matters to me, class, community”</td>
<td>Classroom Observations, Student Interviews Code co-occurrence of ascribing relevance, rejection of relevance, community, school, personal interests &amp; experiences, and interpretation of excerpts</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RQ 3 - Citizen Science Challenge as Promoting Relevance and Agency</td>
<td>Student Online Survey Data Correlations for all responses between items “How I learned today” and “Connects to Challenge”; “How I learned today” and “Matters to me, class, community”</td>
<td>Classroom Observations, Student Interviews Code co-occurrence of challenge with agency codes examined for RQ 1 and relevance codes examined for RQ 2, and interpretation of excerpts</td>
</tr>
</tbody>
</table>
**Quantitative data analysis.** I performed mathematical and statistical analyses of the student online surveys to discern patterns of confirming and disconfirming evidence pertinent to this study’s research questions. These analyses included descriptive statistics to examine patterns of the proportion of students’ responses within and across classrooms and the use of correlations to examine the strength and direction of associations between items of interest.

*Calculating and comparing proportion of item responses for items pertaining to agency and relevance.* I calculated the proportions of student responses for dichotomous items, namely, “I figured out something related to the challenge” (RQ 3) and “What we did or learned about in class today… Matters to me, Matters to the class, Matters to the community” (RQ 2). For the ordinal item, “On the scale of 1 to 5 below, what best describes how you learned today?” (RQ 1) where “1” indicates “The teacher told us everything we needed to learn” and “5” indicates “We figured most things out on our own that we needed to learn,” I treated responses as falling on a continuous scale and calculated the mean of all responses. I also calculated and examined proportions and means of student responses within and across categorical groups (e.g. the percent of students who felt “Like a scientist” in each classroom). This analysis allowed for researchers to compare patterns of students’ experiences of relevance and agency in one classroom to students’ experiences in another. Uneven response rates between classrooms, however, limited interpretations somewhat. Relatedly, the calculation of overall means and proportions did not account for variation in response rates in classrooms (e.g. more responses from one classroom) or for different lessons (e.g. more responses for one lesson), meaning some classrooms and lessons may have had more influence on these statistics than others.

*Correlation calculations for determining associations between items pertaining to the challenge, agency (“figure things out”), and relevance (“me, class, community”) (RQ 3).* In this
study, I also examined correlations between responses for the item “connected to the challenge” with the items on “figure things out” (indexing agency), and “relevance to me, class, community” (indexing relevance) (RQ 3). Given that responses in the survey had either a dichotomous or ordinal form, I employed polychoric and tetrachoric correlation calculations to examine the strength and direction of associations between items (see Drasgow, 1988). These calculations return a Spearman’s Rho coefficient that researchers could interpret using typical guidelines for correlation coefficients (i.e. values range from -1 to +1; stronger associations closer to -1 or +1; no association closer to 0). Importantly, although two variables may have shown a correlation, I could not claim a causal relationship between variables on this evidence alone. Other analyses, namely qualitative analytic approaches, provided more context as to the influence of variables on participants’ experiences. Of note, calculation of correlations utilized all available responses to gain an overall sense of associations between types of responses on the student online survey. This approach does not account for variation in response rates in classrooms (e.g., more responses from one classroom) or for different lessons (e.g., more responses for one lesson), meaning some classrooms and lessons may have had more influence on these statistics than others.

**Qualitative data analysis.** In addition to quantitative techniques, I utilized qualitative analytic techniques in identifying patterns of evidence attending to the study’s research questions. I used qualitative analyses of a corpus of text data comprised mainly of fieldnotes from observations of focus classrooms and transcripts from interviews with focus students and focus teachers. I primarily sought to use qualitative analytic approaches in order to provide insights pertaining to the research questions for this study. In terms of approach, all textual sources of data underwent successive rounds of deductive, theoretically driven coding and
inductive, bottom-up coding primarily to reduce the data and discern productive patterns (Emerson, Fretz, & Shaw, 1995a). Deductive approaches have the researcher fit data into “already established categories” (Emerson et al., 1995a, p. 151). Inductive approaches, on the other hand, have researchers put more emphasis on “developing rather than verifying analytic propositions” (Emerson et al., 1995a, p. 143).

Development of initial coding scheme. Recall that this study seeks to gain insights into how students’ use of science and engineering practices supported their sense of agency (RQ 1), how students perceived the relevance of the unit to themselves, their class, and the community (RQ 2), and the influence of the challenge on agency and relevance (RQ 3). To develop the study’s initial coding scheme, researchers first utilized a deductive approach to establish coding bins for use with interviews and fieldnotes of observations. Drawing from the study’s conceptual framework, CHAT, researchers developed parent coding bins for individuals, community, object, and mediational means. In addition, researchers also created an explicit parent code for agency given its importance within CHAT and as an element of the study. Under individuals, useful for interpreting patterns for RQ 1, RQ 2, and RQ 3, researchers created child code categories for each focus teacher and participant as well as child codes to capture the activity of other important participant groups (e.g. “Parks & Rec”). Under object, researchers included a child code for the challenge (RQ 3), the designed object of activity. Under community, researchers created child codes the classroom or school community (RQ 2), and the broader community (RQ 2) of the city and its neighborhoods. In terms of mediational means, researchers created child codes for various tools known to researchers as already embedded within the unit to see how these may have influenced perceptions of relevance and student agency (RQ 1 and RQ 2). Lastly, under agency, researchers created child codes to capture markers of agency such as choice or control.
(RQ 1) where students have authority in their learning, and effect of actions (RQ 1) or whether participants saw their actions as having an impact or breaking away from previous forms of activity.

Researchers also created codes that directly related to the study’s focus on key demands and approaches for curriculum called for in the Framework: relevance, and the use of science and engineering practices as part of three-dimensional science learning (National Research Council, 2012). Accordingly, researchers created parent bins for relevance and science and engineering practices. Under relevance, researchers created child codes for markers of relevance, such as ascribing relevance (RQ 2) or the denoting something as important or meaningful, rejection of relevance (RQ 2) or denoting something as not important or meaningful, Under science and engineering practices, researchers created child codes for all eight practices (RQ 1; National Research Council, 2012).

Researchers also utilized an inductive approach in drafting the initial coding scheme. Examining the data without thought to preconceived categories, researchers discerned additional codes, as well as additional questions, from reading the data. A review of the data allowed for parent codes to arise inductively, notably adaptation references to capture talk about modifications to the curriculum during its implementation, useful for interpreting patterns of results. Child codes for pre-existing parent codes also arose inductively. Under mediational means, researchers created a child code for non-iHub classroom tools (RQ 1 and RQ2) to capture the use of items outside the design of the unit in order to examine whether these materials supported (or hindered) students’ sense of agency and in seeing their learning as relevant.

Finalizing and applying coding scheme. Researchers sought to measure the reliability of the initial coding scheme and revise it if necessary prior to applying codes to the corpus of
fieldnotes and interview data. Researchers completed an inter-rater reliability test wherein a pair of researchers coded data excerpts from a cross-section of the larger dataset. From this test, each code received a Cohen’s kappa coefficient statistic (Cohen, 1960). To interpret the level of agreement for the resulting Cohen’s kappa values, researchers applied the recommendations of Landis and Koch (1977, p.165), who suggested the following interpretations for a kappa statistic value: less than 0.0 – Poor Agreement; 0.00 to 0.20 - Slight Agreement; 0.21 to 0.40 – Fair Agreement; 0.41 to 0.60 – Moderate Agreement; 0.61 to 0.80 – Substantial Agreement; 0.81 to 1.00 – Almost Perfect Agreement. Researchers deemed codes with Cohen’s kappa coefficient values that fell below 0.5 as problematic and removed them. Researchers calculated the overall reliability between the pair of raters for the revised coding scheme using a pooled kappa statistic (De Vries, Elliott, Kanouse, & Teleki, 2008). The resulting pooled kappa value of 0.79, as interpreted by Landis and Koch (1977), indicated a substantial amount of agreement between raters for the revised coding scheme. Of note, this pooled statistic does not include values for codes where the pair of raters attained a perfect correlation as kappa is technically undefined in such perfect cases. Regardless, researchers obtained a high level of inter-rater reliability for the final coding scheme and applied the coding scheme to all data.

Selection and analysis of excerpts. When applying the coding scheme, I identified excerpts demonstrating patterns of activity that routinely emerged from the data. In addition, I identified anomalous excerpts that did not hold to previously established patterns. In terms of constructing meaning from the data, I sought to move from holistic levels of interpretation across the dataset to more explicit levels of interpretation for each excerpt, which in turn informed the development of new holistic levels of meaning. As such, when I identified excerpts deemed as representative of routine or anomalous patterns these excerpts underwent meaning reconstruction
This process required me to derive possible meaning fields (i.e. possible meanings for each excerpt) through the balanced use of emic and etic perspectives (Maxwell, 2012), along with comparing an activity to similar activities, and through examining the contiguity of participants’ actions as part of a sequence or activity. In addition, I explored higher level meaning fields to perform paradigmatic horizon analysis (Carspecken, 1996). I applied temporal horizon meaning fields to judge how the timing of an activity could give meaning to an excerpt as well as paradigmatic horizon meaning fields to weigh how contextual or background elements, particularly an activity’s social or interactional context, may impart meaning to an excerpt.

**RESULTS**

In this section, I present findings that relate to this study’s three main research questions. I substantiate these findings by presenting and interpreting patterns of evidence that arose from quantitative analyses of all classrooms participating in the pilot followed by patterns of evidence drawn from qualitative analysis of the experiences of teachers and students from two focus classrooms. In addition, where detected, I present anomalous data or patterns of evidence that disconfirm previously established patterns. My three major findings are as follows:

1. **Question 1 – Agency in science and engineering practices.** Students experienced a sense of agency in the unit and while using science and engineering practices. Student responses from across all classrooms suggest students experienced some choice or control over their learning, but the degree to which they did so varied by classroom. Across both focus classrooms, the practice of *planning and carrying out investigations* saw higher incidence of use with markers of agency, such as choice or control or seeing the effects of one’s actions as seen from classroom observations. All four focus students
expressed feeling a sense of agency when engaging in the practices of planning and carrying out investigations and obtaining, evaluating, and communicating information.

2. Question 2 – Relevance to self, class, and community. Students saw their activity in the unit as relevant to different degrees for the community, their class, and themselves. While 64.62% of student responses on surveys and all focus students reported their activity in the unit as relevant to their community, only 29.33% of all survey responses overall and two of four focus students saw their actions as personally relevant. Additionally, the degree to which students saw their activity as relevant to themselves, their class or school, and their community varied by classroom, with evidence from classroom observations suggesting how some teachers purposefully attended to issues of relevance may have led to variation between classrooms.

3. Question 3 – Citizen science challenge as promoting relevance and agency. The challenge supported students in experiencing a sense of agency in the form of choice or a sense of control and seeing the effect of their actions, as well as seeing the relevance of their learning for themselves and their classroom (but not their community). Student surveys showed when students saw connections to the challenge, they tended to experience choice or control, r(1222) = 0.25, p<.05, as well as perceive their activity as relevant to themselves, r(1222) = 0.32, p<.001, and to their class, r(1222) = 0.14, p<.05. All focus students expressed a sense of agency when engaged in the practices of investigating and obtaining, evaluating, and communicating information. All focus students generally found their activity in the challenge to have relevance. However, some expressed that they found the challenge more immediately relevant to themselves and their school and less relevant to a distant community.
Findings in this section will include illustrations of experiences drawn from two focus classrooms. As described previously (see participants section), two classrooms served as focus classrooms in this study: Beth’s biology classroom at the Creative Arts Academy and Clarissa’s biology classroom at the Beacon Community School. Two students from each classroom served as focus students, selected for their willingness to participate and judgments from focus teachers as to their reliability in attending class consistently and participating in the unit. From Beth’s classroom, these students included Casey, a young white male, and Karen, a young female of Asian descent. From Clarissa’s classroom, these students included Isabella, a young Hispanic female, and Eduardo, a young Hispanic male.

**Agency in Science and Engineering Practices (Question 1)**

Students experienced a sense of agency in the unit and while using certain science and engineering practices. However, the degree to which students experienced agency varied by classroom. Across both focus classrooms, the use of *planning and carrying out investigations* occurred along with markers of agency to a greater degree than other practices. Additionally, all four focus students expressed a sense of choice or control or acknowledged the effects of their actions when engaging in activities where they took up the practices *planning and carrying out investigations* and *obtaining, evaluating, and communicating information*.

**Students’ agency in using practices to figure out science ideas differed across classrooms.** In examining students’ sense of agency, I analyzed student online survey data across all classrooms, focusing on an item asking students to rate “On the scale of 1 to 5 below, what best describes how you learned today?” Ratings closer to 5 would indicate that students felt they had more choice or control over their learning that day, an indicator of agency. I calculated the mean score on the item for all classes (see Table 3). Students across all classrooms, on
average, experienced a moderate sense of agency in terms of choice or their sense of control for the days they submitted student online survey as indicated by an overall mean of 3.41. The uneven response rate, however, ranging from 12 to 290 responses per class, suggests some classrooms had more influence on the overall average than others. Some students, such as those in Beth’s classroom, experienced a very high degree of choice or control, while other students, such as those in Teacher B’s classroom, experienced less choice or control. This shows that the teacher students had may have influenced how much choice or control they experienced.

However, small sample sizes for Teacher C and Teacher H indicate responses to only one lesson and should not be extrapolated to represent these students’ greater experience of the unit.

Table 3

<table>
<thead>
<tr>
<th>Classroom teacher</th>
<th>Number of responses</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clarissa</td>
<td>109</td>
<td>3.51</td>
<td>0.86</td>
</tr>
<tr>
<td>Beth</td>
<td>75</td>
<td>3.91</td>
<td>0.95</td>
</tr>
<tr>
<td>Teacher A</td>
<td>99</td>
<td>3.43</td>
<td>1.00</td>
</tr>
<tr>
<td>Teacher B</td>
<td>84</td>
<td>2.99</td>
<td>1.05</td>
</tr>
<tr>
<td>Teacher C</td>
<td>12</td>
<td>3.83</td>
<td>1.03</td>
</tr>
<tr>
<td>Teacher D</td>
<td>193</td>
<td>3.21</td>
<td>1.02</td>
</tr>
<tr>
<td>Teacher E</td>
<td>290</td>
<td>3.43</td>
<td>1.00</td>
</tr>
<tr>
<td>Teacher F</td>
<td>71</td>
<td>3.49</td>
<td>1.09</td>
</tr>
<tr>
<td>Teacher G</td>
<td>146</td>
<td>3.38</td>
<td>1.08</td>
</tr>
<tr>
<td>Teacher H</td>
<td>26</td>
<td>3.35</td>
<td>1.02</td>
</tr>
<tr>
<td>Teacher I</td>
<td>119</td>
<td>3.54</td>
<td>0.95</td>
</tr>
<tr>
<td>Total</td>
<td>1224</td>
<td>3.41</td>
<td>1.02</td>
</tr>
</tbody>
</table>

**Focus classroom findings for agency.** Examination of focus classroom data showed that students in each classroom did experience agency in terms of choice or a sense of control and seeing the effect of their actions in the unit. My analysis revealed that students’ in Beth’s classroom likely experienced a greater sense of agency than students in Clarissa’s classroom, a pattern that corroborates student online survey data. The reasons for this discrepancy between
classrooms centered on how each teacher made adaptations to the unit, with Beth providing less scaffolds and directives for learning and Clarissa providing more scaffolds and directive learning. Additionally, as elaborated below, I found that the practice of planning and carrying out investigations saw high use across both classrooms with markers of agency, such as choice or a sense of control and seeing the effects of one’s actions. My analysis found that all four focus students experienced agency when engaging in the practices of planning and carrying out investigations and obtaining, evaluating, and communicating information. Unit activities in which these practices saw the most use and where students expressed more agency included investigations and presentations for the challenge.

Choice or control and effect occurred differently across focus classrooms. I examined excerpts from focus classroom observations for the occurrence of choice or control, where students have authority over their activity, and effect, where students referenced the impact of their actions, (see Table 4). Inspection of excerpts confirmed that students in both classes experienced choice or control and the effect of their actions, typically while engaged in hands-on investigations and preparing their presentations regarding the challenge. While the pattern of occurrences for each aspect of agency within each classroom show a similar proportion, Beth’s classroom had more observed instances of choice or control and effect than Clarissa’s classroom. Given that each classroom underwent a similar number of observations yielding similar numbers of excerpts, this classroom observation data suggests students in Beth’s classroom may have experienced more markers of agency, which corroborates results from the student online surveys.
Table 4

Comparison of choice or control occurrence in focus classrooms

<table>
<thead>
<tr>
<th></th>
<th>Number of classroom observations (excerpts)</th>
<th>Occurrence of Choice or Control from classroom observations</th>
<th>Occurrence of Effect from classroom observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beth’s Classroom</td>
<td>13 (113)</td>
<td>16</td>
<td>6</td>
</tr>
<tr>
<td>Clarissa’s Classroom</td>
<td>11 (127)</td>
<td>7</td>
<td>3</td>
</tr>
</tbody>
</table>

Adaptations may have led to differences in how students experienced agency. Examining excerpts from interviews and classroom observations, I found some indication that teachers’ instructional approaches, notably adaptations made to the unit, could both support or hinder the development of students’ sense of agency, which provides a possible explanation for the variation indicated between the focus classrooms and possibly other participating classrooms. During observations, Clarissa showed a pattern of modifying materials in the unit to provide additional supports for her students and, at times, a tendency to not let her students “figure out” concepts on their own. Comments from her focus students, such as the following from Isabella, illustrate how her students experienced choice or control during the unit.

Researcher: Mm-Hm. Mm-Hm. How much do you think you figure out stuff versus she just tells you?

Isabella: 50/50. [...]

Researcher: Okay. And what would you prefer?

Isabella: I mean it is useful. I mean it is, it helps me a lot her telling me because I think her telling me, I’ll like it will just stay in my brain and I’ll always like remember that. But I mean finding it yourself, you’re like, “Okay, yeah. I got this.” (Isabella, 9/3/2015)
In Isabella’s opinion, instruction in Clarissa’s classroom provided moderate amounts of choice or control. While Isabella sees some benefit to simply being told an answer, she recognizes that “finding it out yourself” leads to more powerful learning. In contrast to Clarissa’s classroom, observations showed a pattern of Beth taking away existing supports embedded in the unit and letting students have to “figure out” more on their own. Her students expressed that they preferred this approach of more choice and control over their learning, as alluded to in this interview with Karen.

**Researcher:** How does Ms. Brown support your learning in this unit or how has she?

**Karen:** Well she’s told us that, you know, with this information you can go out and make a difference in the world and well like with a lot of things she really lets us explore and then so that’s supporting our learning by letting us sort of figure things out and then because sometimes that is more useful than if we were just taking notes on things. (Karen, Interview, 10/16/15)

In addition to sharing how Beth positions students as agents of change in the world, Karen describes how Beth maintains choice or a sense of control for her students in their learning. Karen describes how in Beth’s classroom she has the opportunity to “figure things out” for herself by exploring in class, an indicator of having choice or control over her learning. She contrasts the approach in Beth’s class to a more direct instructional approach, “taking notes on things,” which she sees as undesirable. The instructional approach she experiences in Beth’s classroom, on the other hand, she sees as useful and as “supporting our learning.”

*Planning and carrying out investigations occurred with markers of agency.* In examining whether and how the use of science and engineering practices promoted students’ sense of agency, I examined excerpts where references to *choice or control* and *effect* occurred with each
of the science and engineering practices across both classrooms (see Table 5). Within Beth’s classroom, the practices of *planning and carrying out investigations*, coinciding while students engaged in labs or investigations, and *developing and using models*, also coinciding with labs and investigations, occurred together more relative to other practices. In Clarissa’s classroom, I observed a higher occurrence for the practice of *planning and carrying out investigations* than other practices with markers of agency. Closer inspection of excerpts showed that the practice most detected as occurring in proximity to instances of *choice or control* and *effect* across both classrooms was *planning and carrying out investigations*, occurring with lab and investigation activities across both classrooms.

Table 5

*Occurrence of practices with choice or control and effect by classroom*

<table>
<thead>
<tr>
<th>Class (n Obs)</th>
<th>Occurrence of choice or control and effect for practices from classroom observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beth’s Classroom (13) [113]</td>
<td>2</td>
</tr>
<tr>
<td>Clarissa’s Classroom (11) [127]</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>2</td>
</tr>
</tbody>
</table>

*Focus students experienced agency when engaging in practices of investigating and obtaining, evaluating, and communicating information.* Examination of excerpts from focus student interviews found that all focus students reported feelings of *choice or control*, usually expressed as having “figured out” something in the unit, or referenced the *effect* of their actions, while describing activities where they engaged in science and engineering practices (see Table 6). Which practices each focus student referenced varied slightly from one student to the next,
however, focus students generally showed a preference for talking about activities that referenced the use of the practices planning and carrying out investigations and obtaining, evaluating, and communicating information, partially replicating patterns seen in excerpts from classroom observations (see Table 5).

Table 6

_Occurrence of practices with choice or control and effect by focus student_

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>out of (total occurrence of practice)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Casey</td>
<td>1 (3)</td>
<td>1 (3)</td>
<td>0 (2)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>2 (4)</td>
<td>0 (0)</td>
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<td>(3) [36]</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Karen</td>
<td>2 (3)</td>
<td>1 (3)</td>
<td>2 (2)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>2 (4)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>(3) [36]</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Isabella</td>
<td>1 (1)</td>
<td>1 (3)</td>
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<td>3 (5)</td>
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<tr>
<td>Eduardo</td>
<td>1 (3)</td>
<td>0 (2)</td>
<td>0 (3)</td>
<td>0 (0)</td>
<td>1 (4)</td>
<td>2 (6)</td>
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<tr>
<td>Total</td>
<td>5 (10)</td>
<td>3 (11)</td>
<td>8 (13)</td>
<td>0 (0)</td>
<td>1 (4)</td>
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</tr>
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</table>

In terms of how the students’ taking up of science and engineering practices supported their sense of agency, the actual use of the practices in the unit positioned students to take on more control of their learning, leading to a sense of agency. Here, Isabella indicates she experienced a sense of agency when engaging in a lesson in which she figured out how to collect data on the quality of soil for potential planting sites for trees, indexing the practice of planning and carrying out investigations.

Researcher: And let me ask you this, when was the last time that you felt like you were doing science in this class?

Isabella: I think when we went outside and when we put those -- I don’t…
Isabella sees her activity in the soil lab as an example of “doing science,” a position of control she came to through her use of the practice of planning and carrying out investigations. She cites that, instead of passively receiving information, she engaged in “actually like experimenting and getting data like for yourself.” This suggests she felt a sense of control and choice over her actions that departs from previous experiences she has had with science class where she experienced less agency in her learning. Having the capacity to exert control of one’s learning while engaging in a practice proved to promote a sense of agency proved a consistent pattern across all focus participants.

**Question 2: Relevance to Self, Class, and Community**

Students saw their activity in the unit as relevant but more towards either the community, their class, or themselves, and these proportions varied by classroom. While 64.62% of student responses on surveys and all focus students reported their activity in the unit as relevant to their community, only 29.33% of all survey responses overall and two of four focus students saw their actions as personally relevant. Examination of focus student interviews suggests that two of four students saw the content of their learning in the unit as inconsequential to their personal lives or
interests, but still consequential to the community. Two students who made connections in the unit to their personal lives and interests, or saw themselves as members of the broader community, saw their learning as more personally relevant, showing how different forms of relevance can overlap and inform one another.

**Students perceived relevance to the community over personal relevance.** In examining whether and how students perceived their activity in the unit as relevant or meaningful, I examined responses from students on the student online survey across all participating classrooms. Of 1224 student responses to the prompt “What we did or learned about in class today…(choose one or more)”, 1146 responses, or 94.6% percent of all responses, reported seeing relevance of some form, either “Matters to me,” Matters to the class,” or “Matters to the community.” In total, for 64.62% of responses, students indicated their learning mattered to the community; for 38.97% of responses, students indicated their learning mattered to the class; and for 29.33% of responses, students indicated their learning mattered to themselves. These results suggest that while students did see relevance of some form in their activity in the unit, they saw it as mostly relevant for others in the community rather than for themselves or their class.

Further analysis revealed that the proportion of student responses among the three possible categories, “me,” “class,” and “community” differed amongst classrooms (see Table 7). Despite differences in the proportion of responses between classes, all 11 participating classrooms had similar rankings for the three response types. For all classrooms, “Matters to the community” had the highest proportion or percentage value, followed by “Matters to the class,” and “Matters to me.” Caveats to the student online survey data still hold in that certain classrooms appear to have only submitted one set of responses for one lesson (e.g. Teacher C and
H), thus interpreting these results as indicative of a student’s broader experience in the unit would be ill-advised.

Table 7

*Percentage of student responses for relevance by classroom*

<table>
<thead>
<tr>
<th>Classroom teacher</th>
<th>Number of responses</th>
<th>Matters to me (% of responses)</th>
<th>Matters to class (% of responses)</th>
<th>Matters to community (% of responses)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clarissa</td>
<td>109</td>
<td>28.44</td>
<td>38.53</td>
<td>66.97</td>
</tr>
<tr>
<td>Beth</td>
<td>75</td>
<td>36.00</td>
<td>40.00</td>
<td>77.33</td>
</tr>
<tr>
<td>Teacher A</td>
<td>99</td>
<td>26.26</td>
<td>27.27</td>
<td>72.73</td>
</tr>
<tr>
<td>Teacher B</td>
<td>84</td>
<td>30.95</td>
<td>54.76</td>
<td>60.71</td>
</tr>
<tr>
<td>Teacher C</td>
<td>12</td>
<td>33.33</td>
<td>50.00</td>
<td>66.67</td>
</tr>
<tr>
<td>Teacher D</td>
<td>193</td>
<td>26.94</td>
<td>36.27</td>
<td>55.44</td>
</tr>
<tr>
<td>Teacher E</td>
<td>290</td>
<td>23.10</td>
<td>40.00</td>
<td>58.28</td>
</tr>
<tr>
<td>Teacher F</td>
<td>71</td>
<td>46.48</td>
<td>56.34</td>
<td>66.20</td>
</tr>
<tr>
<td>Teacher G</td>
<td>146</td>
<td>32.19</td>
<td>39.04</td>
<td>80.82</td>
</tr>
<tr>
<td>Teacher H</td>
<td>26</td>
<td>15.38</td>
<td>53.85</td>
<td>65.38</td>
</tr>
<tr>
<td>Teacher I</td>
<td>119</td>
<td>35.29</td>
<td>24.37</td>
<td>59.66</td>
</tr>
<tr>
<td>Total</td>
<td>1224</td>
<td>29.33</td>
<td>38.97</td>
<td>64.62</td>
</tr>
</tbody>
</table>

Focus classroom findings for relevance. Examination of data for focus classrooms occurred with the aim of gaining more insight as to how students perceived and ascribed relevance to their activity in the unit. My analysis found some evidence that Beth actively sought to support students in ascribing relevance versus Clarissa, which may partially explain some variation observed between classrooms in how students ascribed relevance. I examined how focus students ascribed or rejected relevance and found this provided an overall pattern where focus students saw their learning as more relevant first to the community, then their class, and lastly themselves—the same pattern observed in student online surveys. My interpretation of excerpts from focus students provided some insights into this recurrent pattern. Some students saw the content of the unit as irrelevant to themselves in that it did not connect with their personal experiences, interests, or aspirations, but felt it still useful to their community, which,
consequently, they may not necessarily include themselves in. Students who saw themselves as part of the larger community or made meaningful connections to the unit from their personal lives, experienced more personal relevance.

*Focus classrooms differed in actively ascribing relevance.* In an attempt to gain insight into the variation seen between classrooms on the student online surveys in how students assigned relevance for their learning, I examined excerpts where ascribing relevance, essentially when someone deems something meaningful or important, occurred for both Beth and Clarissa’s classrooms. Beth’s classroom (13 observations with 113 excerpts) had 6 occurrences of ascribing relevance to 3 from Clarissa’s classroom (11 observations with 127 excerpts). No instances of rejection of relevance, where students did not see their learning as relevant, occurred in classroom observations. Inspection of excerpts suggests that Beth made more active efforts than Clarissa to have students see the relevance of their learning, typically by connecting their learning to goals and problems addressed by the challenge. This typically consisted of a simple conversation with students in which Beth would begin by saying “We’re doing this all because…” (Fieldnotes, 9/15/15). Teachers actively supporting students in ascribing relevance to their learning may at least partially explain some variance observed in results for relevance between classrooms.

*Community relevance favored over personal relevance by focus students.* I examined excerpts from focus student interviews for the occurrence of students ascribing relevance to something in the unit or the rejection of relevance with references to personal interests or experiences, students’ class or school, or the community. This resulted in a pattern suggesting students saw their activity as more relevant to the community than themselves (see Table 8). Inspection of individual excerpts did find that all focus students referenced the community while
ascribing relevance to their learning more than when they referenced their class or school or personal interests or experiences. Furthermore, inspection of excerpts confirmed that excerpts for rejection of relevance also supported this pattern. Specifically, focus students supplied more instances of rejection of relevance in terms of their personal interests and experiences than rejection of relevance in terms of the community.

Table 8

*Ascribing of relevance and rejection of relevance by focus student*

<table>
<thead>
<tr>
<th>Student (n interview)</th>
<th>Personal Interests or Experiences &amp; Ascribing Relevance (Rejection of Rel.)</th>
<th>Class or School &amp; Ascribing Relevance (Rejection of Rel.)</th>
<th>Community &amp; Ascribing Relevance (Rejection of Rel.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Casey (3) [36]</td>
<td>2</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Karen (3) [36]</td>
<td>1 (1)</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Isabella (3) [51]</td>
<td>0 (4)</td>
<td>3 (2)</td>
<td>4 (1)</td>
</tr>
<tr>
<td>Eduardo (3) [47]</td>
<td>3</td>
<td>1</td>
<td>4 (1)</td>
</tr>
<tr>
<td>Total</td>
<td>6 (5)</td>
<td>11 (2)</td>
<td>19 (2)</td>
</tr>
</tbody>
</table>

Closer examination of focus student interview excerpts provides some potential insights as to why focus students saw their learning as more relevant to the community versus themselves or their class or school. Students in both classrooms tended to see their activity in the unit as relevant to the community in that they felt that problems and issues that they had learned about in class directly pertained to their community. This excerpt from an interview with Karen shows how she saw the threat of an invasive species, the emerald ash borer, as relevant to her community.

Researcher: What about others? Does what you’ve learned matter to others?

Karen: Yes, because the emerald ash borer affects everyone in the city since it’s
spreading here from nearby cities and there are lots of ash trees here.

Researcher: Why is it important for the community to know that?
Karen: So that they know why their trees are dying and what they can do about it.

(Karen, Interview, 11/05/15)

Karen sees her learning as relevant to the community in that the community faces a threat from the emerald ash borer that she had learned about in class. She sees the effects of this threat as having implications for everyone in the community. Notably, she sees her learning as possibly a means to mitigate the effect of the emerald ash borer if the community became aware of what she had learned in class. Across the four focus students, beyond seeing what they learned as having implications for the community, the notion that students could leverage their learning in service to the community also proved a common theme that led students to also see their activity in the unit as relevant to the community. Eduardo, for example, when asked if his learning mattered to the community replied, “Yes because I think that it like we provided this research, it should be like brought into like action, like how we’re doing planting the tree.” (Eduardo, Interview, 10/22/15).

Two of four focus students did not find their learning personally relevant. In terms of how students in focus classrooms saw their learning as personally relevant, two of the four focus students, Isabella and Karen, showed indications that they did not see their learning as personally relevant or meaningful. I examined excerpts where these students rejected the relevance of the unit for themselves and found that they both saw the content of the unit as inconsequential to their personal experiences and interests (see Table 8). This interview excerpt from Isabella provides an example of when she expressed she did not find her learning personally relevant but did see it as still having relevance to the community.
Researcher: What you learned, how useful is it? [...] 

Isabella: I don’t know if it’s going to be something I’m going to use in my future but it was cool to learn, it was cool to learn about it but I don’t know if it’s something I’m going to use like in life when I get older.

Researcher: Do you see any situation where it might be useful? 

Isabella: I think like if my community is trying to plant a tree and they’re asking like what ideas and stuff like that put in like ideas into that. (Isabella, Interview, 11/5/15)

Though she saw the content of her learning as “cool,” Isabella does not see it as useful in terms of her personal interests and aspirations (“when I get older”). Reflecting patterns seen across data in this section, Isabella, however, does see her learning as applicable and relevant to the community despite not finding it personally relevant. That Isabella sees no meaningful connection between her learning and her personal experience and aspirations but does see a connection between her learning and the community suggests that she may see the community as separate from herself. The relevance to the community that she sees, she does not see for herself.

Two of the focus students, Casey and Eduardo, did see their learning and activity in the unit as personally relevant. For both of these students, they made meaningful connections to what they learned and experienced within the unit to personal experiences or interests outside of the classroom. In this excerpt, Casey talks about why he sees his learning in the unit as personally relevant.

Researcher: Okay, does what you’ve learned so far does it matter to you? 

Casey: It does because there is a lot of different things that we’ve learned that are really impacting or will impact the things that just go around or have been
there that I just grew up with. Like there is a bunch of trees just in the area I live […] And so if all that is gone […] it’s going to be a large impact.

Casey saw what he has learned as having personal relevance due to connections he saw in the unit to his personal experiences. What he has learned in the unit matters because Casey sees it as connected to where he lives and has grown up. Moreover, stemming from what he has learned, Casey sees the “bunch of trees” in his neighborhood as about to undergo a “large impact,” an impact he will personally experience, likely supporting personal relevance. In essence, Casey, sees his learning as relevant to his neighborhood community, and seeing himself as part of this community, he also experiences personal relevance with the unit.

**Question 3 - Citizen Science Challenge as Promoting Relevance and Agency**

The challenge supported students in experiencing a sense of agency in the form of choice or a sense of control and seeing the effect of their actions, as well as seeing the relevance of their learning for themselves and their classroom (but not their community). Student responses on surveys indicated that when students saw connections to the challenge, they tended to experience choice or a sense of control, $r(1222) = 0.25, p<.05$, as well as perceive their activity as relevant to themselves, $r(1222) = 0.32, p<.001$, and to their class, $r(1222) = 0.14, p<.05$. All focus students expressed a sense of agency, particularly when engaged in science and engineering practices of *investigating* and *obtaining, evaluating, and communicating information*. All focus students generally felt their activity in the challenge had relevance in some form. Some focus students, however, expressed that they found the challenge more immediately relevant to themselves and their school and less relevant to a distant community.

**Students experienced choice or a sense of control and saw their learning as relevant**
to themselves and their class when engaged in the challenge. I examined student online survey data for indications of how the challenge may support students in developing a sense of agency. This analysis focused on the scaled item indexing choice or control, “On the scale of 1 to 5 below, what best describes how you learned today?” with “5” indicating more choice or control. I examined whether student responses to this scaled item correlated with responses of whether students felt their learning connected to the challenge. This analysis showed a small positive correlation between these groups of responses, $r(1222) = .25, p<.05$. This suggests the possibility that when students across classrooms engaged in activities related to the challenge they experienced greater feelings of control in their learning, a marker of agency. Of note, this calculation does not attend to the variation of response rates in the clustered nature of the data, meaning some classrooms and lessons may have had more influence on this statistic than others.

Examination of student online survey data also indicated that when students saw their learning as connected to the challenge, they also denoted their learning as relevant in certain ways. I found a moderate positive correlation between when students indicated their learning connected to the challenge and when they indicated their learning “matters to me,” $r(1222) = 0.32, p<.001$. Additionally, I found a small positive correlation between when students indicated their learning connected to the challenge and when they indicated their learning “matters to the class,” $r(1222) = 0.14, p<.05$. However, I did not find a significant correlation for when students indicated a connection to the challenge and “matters to the community.” This suggests that the relationship between the challenge and the community may not have been perceived or acknowledged by students across all classrooms. Of note, these calculations did not attend to the variation of response rates in the clustered nature of the data, meaning some classrooms and lessons may have had more influence on this statistic than others.
Findings from focus classroom data for how challenge influenced agency and relevance. My examination of data from Beth and Clarissa’s classrooms provided some insights as to how the challenge supported students’ sense of agency and how they perceived relevance in their activity. For all four focus students, the challenge engaged them in using science and engineering practices, particularly planning and carrying out investigations and obtaining, evaluating, and communicating information, feeding into how the challenge sought to provide students with choice or control in the process of developing their solution and the opportunity to achieve a desired outcome of actually implementing their solution. While all focus students expressed that they saw their learning as relevant in relation to the challenge, particularly towards their class or school, Karen felt that her activity in the challenge may have had more relevance for herself and her school due to the immediacy of planting a tree on her school grounds. Also, Isabella and Eduardo indicated that they felt the community might react with indifference to the challenge because they saw people in the community as too separate or lacking knowledge about the challenge.

Use of science and engineering practices provided for agency in the challenge. To examine the role of the challenge in shaping students’ sense of agency, I first examined excerpts from classroom observations (Beth: 13 observations, 113 excerpts; Clarissa: 11 observations, 127 excerpts) where references to choice or control and effect occurred with references to the challenge across both focus classrooms, which identified 7 excerpts from Beth’s classroom and 5 from Clarissa’s. Examination of these 12 excerpts found that students expressed a sense of agency when using science and engineering practices towards the challenge; 5 excerpts involved students engaged in obtaining, evaluating, and communicating information to prepare their tree presentations, 5 excerpts involved students planning and carrying out investigations for various
labs and investigations closely tied to the challenge, and 2 excerpts where students first learned about the challenge and engaged in asking questions and defining problems. This suggests the practices for investigating and obtaining, evaluating, and communicating information, in particular, seemed to support students’ agency in the challenge.

Examination of how focus students took up science and engineering practices in relation to the challenge provided insights into how the science and engineering practices in pursuit of the challenge could promote agency. Echoing patterns seen in classroom observation data, the focus students referenced engagement in the practices of planning and carrying out investigations and obtaining, evaluating and communicating information more than other practices when expressing a sense of agency and discussing activities related to the challenge, however, the practices of analyzing and interpreting data and argumentation with explanation, also showed notable uptake in terms of proportions (see Table 9). Examination of individual excerpts confirmed that focus students expressed a marked sense of agency, usually in terms of choice or a sense of control, when engaging in the challenge and while using the practices of investigating and obtaining, evaluating, and communicating information, suggesting these two practices supported students more than others in taking ownership of the process of the challenge and in actually completing the challenge.
Table 9

Occurrence of practices with choice or control/effect and challenge by focus student

<table>
<thead>
<tr>
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<td>(n excerpts)</td>
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<td></td>
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<td></td>
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<td>Casey (3) [36]</td>
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<td>0 (0)</td>
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<tr>
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<td>2 (2)</td>
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<td>1 (4)</td>
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<tr>
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<td>1 (1)</td>
<td>1 (3)</td>
<td>3 (6)</td>
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<td>0 (0)</td>
<td>2 (5)</td>
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<tr>
<td>Eduardo (3) [47]</td>
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<td>0 (2)</td>
<td>0 (3)</td>
<td>0 (0)</td>
<td>0 (4)</td>
<td>2 (6)</td>
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<tr>
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<td>0 (0)</td>
<td>0 (4)</td>
<td>5 (19)</td>
<td>0 (0)</td>
<td></td>
</tr>
</tbody>
</table>

The focus students took up science and engineering practices in ways that supported the qualities of the challenge intended to foster student agency. The challenge sought to position students to have choice or control in that they actually develop a solution themselves and have the power to choose which tree to plant. In addition, the challenge sought to provide students with experiencing the effect of their actions through disseminating their knowledge to the community through the local Parks & Recreation department and in actually planting a tree. This excerpt from Karen, shows how her engagement with the practice of *obtaining, evaluating, and communicating information*—in conjunction with the challenge—provided a marked sense of agency.

Researchers: Let me ask you this, when was the last time you felt that you figured something out on your own in this unit?

Karen: Well I guess when we were working on our individual trees and like how like figuring out how to convince the class that they were the best tree we
researched all of that ourselves and figured out why we wanted our tree and why we like because we all got invested in our own trees. (Karen, Interview, 10/16/15)

In her response, Karen describes her activity in preparing a presentation of her tree recommendation. She experienced a sense of control in doing research on her tree with her group and in preparing her group’s presentation, using the practice obtaining, evaluating, and communicating information to develop a solution to the challenge. In addition, Karen expresses investment in the process of developing her presentation for the challenge, indicating that she sees the possibility of having her choice of tree become chosen by the class as achieving a desired effect, a possibility made possible by the nature of the challenge.

Students in focus classrooms saw their learning as relevant when engaged in the challenge. To examine how engagement with the challenge may have influenced how students in Beth and Clarissa’s classrooms perceived the relevance of their learning, I first analyzed excerpts from observations of both focus classrooms (Beth: 13 observations, 113 excerpts; Clarissa: 11 observations, 127 excerpts) where ascribing relevance and rejection of relevance occurred with references to the challenge, leading to the identification of two excerpts for Beth’s classroom and two excerpts for Clarissa’s classroom. Inspection of these few excerpts revealed that students in both classrooms did express their learning and activity in the challenge as having relevance, notably in regards to preparing their presentations for the challenge, which had the possibility of being shared with the community. Also of note, Beth’s excerpts revealed efforts to routinize the act of having students see the purpose of their learning, “We’re doing this because…?” (Beth, Fieldnotes, 9/11/15). These attempts to promote coherence continually foregrounded the challenge and provided potential opportunities for students to recognize activity related to the
challenge and to see that activity as relevant. Clarissa made no such attempts.

Examination of focus student interviews provided a sense of the degree as well as the direction in which these students ascribed relevance: to themselves, their class, or community. I examined excerpts from the four focus students’ interviews where references to the challenge and ascribing and rejection of relevance occurred with references to personal interests or experiences, students’ class or school, and the community (see Table 10). Examination of excerpts did generally show that all four focus students found their activity in the challenge as relevant, particularly for their class or school. Students most often referenced activities that directly related to the challenge when ascribing relevance, notably preparing their presentation of their tree choice for the challenge or carrying out investigations, primarily the soil lab, on their school grounds. Eduardo for example, saw his activity in the soil lab as relevant to his school: “Like we’re kind of helping them know the information about the school grounds” (Eduardo, Interview, 9/3/15).

Table 10

Relevance with the challenge by focus student

<table>
<thead>
<tr>
<th>Student (n interview)</th>
<th>n excerpts</th>
<th>Occurrence of Ascribing Relevance or (Rejection of Rel.) &amp; Challenge for each response category</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Personal Interests or Experiences</td>
</tr>
<tr>
<td>Casey (3) [36]</td>
<td>36</td>
<td>0</td>
</tr>
<tr>
<td>Karen (3) [36]</td>
<td>36</td>
<td>2</td>
</tr>
<tr>
<td>Isabella (3) [51]</td>
<td>51</td>
<td>0 (2)</td>
</tr>
<tr>
<td>Eduardo (3) [47]</td>
<td>47</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>2 (2)</td>
</tr>
</tbody>
</table>
While the four focus students overall did not provide a pattern that replicated those seen in the student online surveys, some excerpts from the focus student interviews bear further scrutiny as they may provide some insights into those patterns. Examination of Karen’s excerpts, in particular, provided some potential insights into patterns seen in the student online surveys. In Karen’s response below to the prompt of whether what she learned so far matters to her, she shows that she felt that the challenge, which she equates to the “planting trees,” applied more to her school and herself.

I think that the planting trees does matter because it’s our school and somewhere that we go every single day so planting trees is going to be a good thing for us. (Karen, Interview, 9/11/15)

In talking about whether she found her learning personally relevant, Karen sees the result of the challenge (“planting of the tree”) as relevant to the school because of her and her classmates’ immediacy to it (“somewhere we go every single day”). In a later interview, her response to the same prompt again shows that the immediacy of the challenge determines its relevance, this time clearly for herself.

It matters to me, well what matters to me is the planting of the tree at the school because I think that’s really cool since I’m here every day and that’s something that like applies to my life more than trees outside of the school I guess. (Karen, Interview, 10/16/2015)

The fact that the tree is close to where Karen spends a significant amount of time makes the challenge (“planting of the tree”) more personally relevant. Moreover, she sees trees not in her vicinity as less relevant. This pattern of results may at least partially explain the significant correlations seen for when students saw their learning as connected to the challenge and also relevant to themselves and their school.
In terms of providing an explanation for the lack of a significant correlation on the student online surveys for when students saw their learning as connected to the challenge but did not see it as relevant to the community, excerpts from focus student interviews also provide some possible insight. In examining when students indicated a rejection of relevance for the community, some students saw the possibility that the community would not strongly resonate with the challenge. This excerpt from Isabella shows that she feels the community may respond with indifference to their activity in the challenge.

Researcher: So what about for folks in the community do you think it matters for them? […]

Isabella: I don’t know I just think that “Hey look they’re planting a tree that’s cool” but I don’t think they’d want to stop and ask why we’re planning a tree and are we from a school or what. They would just be like planting a tree, cool. (Isabella, Interview, 10/15/15)

Isabella notes that the community would see the planting of a tree as a positive but sees the community as too separate from the challenge to see it as meaningfully relevant, even suggesting that the community would not have the desire to learn more about her school’s activity.

Similarly, Eduardo, referring to his research for the challenge and whether it should matter to the community, stated, “It should but some people do not have to worry about these things.” (Eduardo, Interview, 10/22/15). That the community “should” see his activity on the challenge as relevant but does not suggests Eduardo sees the community as either too distant from his experiences to care as he does or they are indifferent.

**DISCUSSION**
This study examined whether the implementation of a biology unit organized around a citizen science challenge supported students in seeing their learning as more relevant and provided opportunities for students “to act (not merely to know)” (Eisenhart et al., 1996, p.282), to experience meaningful agency in the context of using science and engineering practices. This study showed that putting students in a position to experience agency, to “figure out” (Reiser, 2014) their learning, can lead students to better experience and understand how scientists actually work (National Research Council, 2012). While other studies have shown that placing students in empowering positions can support identification with the enterprise of science (Morozov et al., 2014), this study shows how a sense of choice or control can occur through intentionally engaging students’ in three-dimensional science learning (National Research Council, 2012), particularly through deep engagement in the science and engineering practices planning and carrying out an investigation and obtaining, evaluating, and communicating information. This finding supports assertions made in the Framework on the necessity of engaging in the practices to achieve meaningful science learning. While this study singles out these practices as particularly conducive for supporting meaningful science learning, we emphasize that these practices occurred in conjunction with other practices (Bell et al., 2012). This study also showed that overly scaffolding or directing students’ use of science and engineering practices, essentially “hyper-mediation” (Gutierrez & Stone, 2002), can lessen students’ sense of agency. This calls attention to the need for supporting teachers in creating adaptations that balance students’ agency while still proving conducive to learning and instruction remains a challenge for curriculum designers.

This study also found evidence that students saw their learning and activity in the unit as relevant in ways that break from traditional forms of science education and as called for in the
Building on previous work related to relevance (Polman, 2012), this study considered multiple forms of relevance. This study showed that students may ascribe relevance to themselves, their class, and their community differently, a key finding with implications for the design of curricular materials and what designers may have to attend to in order to achieve meaningful science learning. Specifically, this study showed that students generally saw their learning as most relevant to the community but not to themselves, likely lessening the overall impact of the unit in terms of more meaningful learning for students. Addressing this issue, this study showed, likely requires better promoting connections between the content of the unit and students’ personal experiences, interests, and future aspirations, as called for by the Framework (National Research Council, 2012). Relatedly, this study found some evidence of the need for students, in a unit such as this centered on the community, to see themselves as members of the community and their learning as personally relevant in this way. This study may have identified what may prevent students from achieving more personal relevance in their learning, however, this study found few concrete strategies to promote students in making personal connections to the content of their learning and fostering a sense of inclusion in the greater community, the focus of efforts in a citizen science orientation. While the practical measures (Bryk, Gomez, Grunow, & LeMahieu, 2015) employed in this study offer teachers a means to at least assess how students see their learning as relevant, approaches for how to actually support students in seeing their learning as relevant in multiple ways are still needed.

In addition, this study also found that the challenge supported students in experiencing a sense of agency and also supported students in seeing their learning and activity as relevant to themselves and their classroom or school (but not their community). This study stands unique in
embedding a citizen science challenge within a formal school curriculum in order to address issues of equity, in terms of attempting to provide *all* students with access to meaningful science education (National Research Council, 2012). In addition, this study stands in contrast to previous forms of citizen science that did not allow for students to meaningfully experience choice or a sense of control (Lakshminarayanan, 2007). This study showed that when students engage with a citizen science challenge, that such activity can engender a strong sense of agency, particularly in regards to choice or a sense of control and feeling that their actions can have a meaningful effect. This study also provided potential design principles for developing and embedding a citizen science challenge within formal settings. While deeply tied to its locale, features of the challenge, such as positioning students to have choice or control over enacting an actual effect on the world outside the classroom and requiring deep engagement with practices, seem transferrable to other curriculum efforts in other locales. This study, however, also showed the limitations and challenges of utilizing a citizen science challenge. Notably, whereas students saw their learning in the unit as relevant to the community overall, this study found that they may have not seen the *challenge* as particularly relevant to the community. Students found the immediacy of planting the tree on their school campus as more relevant to themselves and their school. However, such limiting the citizen science challenge, in terms of planting of trees, to schools only may have led students to not see their activity in the challenge as meaningful to the community. This suggests a need for better integrating the involvement of the community (see Roth & Lee, 2004), and also reinforces the need for structures that purposefully support students in considering how their learning relevance that can take multiple forms.

This study had certain limitations. First, the student online survey data had variation in response rates for each classroom and for each lesson. For example, certain classrooms
submitted only one set of responses for one lesson, and certain lessons, particularly at the beginning of the unit, had a greater number of responses than other lessons in the unit. Besides direct classroom comparison of proportions of responses on items, this has implications for the interpretation of overall means for responses to a single item (e.g. overall means for responses to “matters to me, class, and community”) and interpretation of correlations between student responses (e.g. overall correlations between responses to “matters to me, class, and community” and “connects to the challenge”). As the calculation of overall means and correlations did not account for variation in response rates in classrooms or for different lessons, some classrooms and lessons may have had more influence on these overall statistics. Second, classroom observations did not always capture the same lessons between classrooms. Teachers made instructional decisions to lengthen, shorten, and even ignore entire lessons in the unit. While having teachers engage in the same lessons for each observation would have proven ideal, it did not prove practical. This limitation complicates comparisons between classrooms, particularly in terms of comparing coding co-occurrences.

CONCLUSION

This study sought to examine how a citizen science challenge within formal school settings could lead to more meaningful learning where students saw their learning as relevant beyond the confines of the classroom and had the opportunity truly “to act (not merely to know)” (Eisenhart, et al, 1996, p.282). Congruent to these aims, this study sought to see how this curricular effort could support the vision of reform efforts in *A Framework for K-12 Science Education* and the Next Generation Science Standards, where students ideally see their learning as relevant and have the opportunity to experience agency while engaging in science and engineering practices (National Research Council, 2012; NGSS Lead States, 2013). This study
has shown that a unit centered around a citizen science challenge for which students develop a solution through the use of science and engineering practices can lead students to experience meaningful science learning that surpasses limitations seen in other curricular formats such as project-based learning, in terms of more meaningful relevance and agency, and especially beyond the traditional format of the science classroom (Engeström, 1991). Students become agentic and see the worth of their learning.

In addition, this study has highlighted some of the challenges of implementing the complex design of a citizen science challenge at scale with the intent of providing all students with access to curricular materials, so that all students can experience more meaningful science learning as envisioned in the Framework (National Research Council, 2012). Chiefly, in examining the effect of the unit across various classroom settings, variation amongst and between classrooms in terms of how students experienced a sense of agency in the curriculum and how students perceived the relevance of their learning shows that students in some classrooms may have had more meaningful science experiences than others. How teachers actually took up the unit for their particular classroom likely influenced how students experienced the unit and the quality of their experience in terms of the relevance of their learning and their sense of agency. Between the two focus classrooms, for example, efforts made by one classroom teacher to adapt and modify the unit—removing what she felt were unnecessary scaffolds for her students—led her students to feel an increased sense of agency. In contrast, modifications and adaptations seen in the other focus teacher’s classroom, coupled with her slightly more direct instructional style, may have led her students feel a decreased sense of agency. Overall, students in these two focus teachers’ classrooms showed higher than average indicators of agency and relevance, however, the issue of adaptation remains. Teachers will
invariably adapt curricular materials to better fit their instructional styles and what they perceive as the needs of their students.

How to design for the inevitable adaptations that will occur during the implementation of curricular materials so that *all* students still experience the underlying goals of a curriculum intended by designers—such as an increased sense of agency or perceiving their learning and activity to have relevance—proves a difficult issue, but one that learning scientists and curriculum developers must attend to. While some adaptations by teachers can definitely prove fruitful for student learning, others may prove less so. Curriculum designers must determine how to provide curricular materials that allow for teachers to leverage their judgment and expertise while also ensuring that core underlying design principles shown to support meaningful science learning do not become lost in implementation. For example, the unit in this study should likely always include centrally positioning the citizen science challenge in instruction and having students engage in “figuring out” their learning through science and engineering practices, as this study has shown these principles can support more meaningful science learning.

Lastly, while this study has shown how having students engage in science and engineering practices towards a citizen science challenge can lead to meaningful science learning, the potential impact of such an approach for students in the future will depend on what happens next. In this study, students may have planted their trees and, for all intents and purposes, the challenge had concluded, but what students gained from their participation in the unit, a nascent sense of agency and seeing their learning as meaningful and relevant, may yet still linger. Providing students with additional opportunities to engage with challenges they find relevant over time and where they can continue to develop their agency has the potential for students to become individuals more apt “to act (not merely to know)” (Eisenhart, et al, 1996,
p.282). Achieving this aim calls for the development of new curricular materials, organized around challenges in different science domains and at different grade levels, as well as research on their implementation in formal settings.
CHAPTER IV

ARTICLE 3

Implementation of a Novel Professional Development Program to Support Teachers’ Understanding of Modeling

by

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ABSTRACT

This study examines the implementation of a novel professional development program, the Next Generation Science Exemplar (NGSX), within a large, urban school district. The NGSX seeks to promote K-12 teachers’ understanding of the significant shifts called for in the Next Generation
Science Standards (NGSS). Utilizing ethnographic data collection methodologies, researchers compiled data on how elementary, middle, and high school teachers engaged with the NGSX’s unique mix of in-person PD activities, web-based interactions, and individual classroom applications of tools and ideas. This study examined how the NGSX supported teachers in gaining a deeper understanding of the NGSS, particularly with respect to the science and engineering practice of developing and using models. Results indicate that (1) among the practices emphasized in the NGSX, teachers oriented primarily to the practice of developing and using models; (2) the facilitation of the NGSX by local administrators led to some teachers’ disengagement with the professional learning experience; (3) the sequence of investigations and the building of specific models, interleaved with discussion activities and video presentations, helped build some teachers’ understanding of developing and using models; (4) the largest uptake of tools from the NGSX by teachers for use in their classrooms occurred with talk moves, public representations, and specific models from the NGSX. Attempts to support teachers in bringing their classroom experiences of using tools from the NGSX back to the PD setting in order to further teachers’ learning proved largely unsuccessful.

**IMPLEMENTATION OF A NOVEL PROFESSIONAL DEVELOPMENT PROGRAM TO SUPPORT TEACHERS’ UNDERSTANDING OF MODELING**

This study examines how and to what degree the Next Generation Science Exemplar (NGSX), a novel hybrid professional development (PD) program utilizing both in-person and online activities occurring across PD and classroom settings, supported the capacity of teachers in a large, urban school district to implement the vision for science education described in *A Framework for K-12 Science Education* (*Framework*; National Research Council, 2012) and the Next Generation Science Standards (NGSS; NGSS Lead States, 2013). Achieving this ambitious
vision of reform poses a significant challenge to states and districts, as it calls for significant shifts in science instruction. Notably, instruction should provide students with “three-dimensional” science learning experiences where they engage with science and engineering practices to build understanding of disciplinary core ideas and crosscutting concepts over time (National Research Council, 2012). The professional development offered through the NGSX aimed to support teachers in making these shifts in science instruction.

A key focus of effort within the NGSX is developing teachers’ capacity to have their students meaningfully engage with science and engineering practices, notably the practice of developing and using models. Teachers’ understanding of what constitutes a scientific model and how to effectively have their students engage in the practice of modeling diverges from that of science education researchers (Van Driel & Verloop, 1999; 2002). Acknowledging the need to better understand teacher learning related to the practice of modeling and given that modeling, as one of the eight practices identified by the authors of the Framework (National Research Council, 2012), has a prominent role in supporting the three-dimensional science learning, this study places a particular emphasis on examining how the NGSX may support teachers’ capacity to meaningfully engage their students in developing and using models.

There is broad recognition that increasing teachers’ understanding of the practice of developing and using models, as well as their capacity to support the district’s efforts to adopt the NGSS, will require educational systems to provide effective teacher development opportunities with these specific aims in mind (National Research Council, 2007, 2012, 2015a; Wilson, 2013). Examining how local facilitators implement the NGSX offers the opportunity to determine how the design of the NGSX supports teachers in increasing their understanding of the practice of modeling and their capacity to implement instruction aligned to the NGSS. Of
particular interest is how a format that spans an extended period of time in which teachers attend PD together, try things out in their classroom, and discuss their classroom practice in subsequent sessions might support deepening understanding of the practice of modeling. By examining the implementation of the NGSX by local facilitators, we also sought to generate insights as to how and why designs for professional development are modified in local contexts, and whether those modifications maintain integrity to the design of NGSX. Specifically, this study poses three research questions:

1. How did the activities and tools embedded within the NGSX program mediate the development of teachers’ understandings of the practice of modeling and the NGSS?

2. How did classroom adaptation and implementation of activities and tools from the NGSX program mediate the development of teachers’ understandings of the practice of modeling and the NGSS?

3. How did local facilitators’ implementation of the NGSX support or hinder building teachers’ understanding of the practice of modeling and the NGSS?

POLICY CONTEXT OF THE STUDY: NEXT GENERATION SCIENCE STANDARDS

In 2012, the National Research Council (NRC) released *A Framework for K-12 Science Education: Practices, Cross-Cutting Concepts, and Core Ideas* (National Research Council, 2012). In this comprehensive document, often simply called the *Framework*, a panel of experts developed a new, ambitious vision for science education at the primary and secondary level. This vision became the basis for the development of the Next Generation Science Standards (NGSS) released in April, 2013 (NGSS Lead States, 2013). Twenty-six states and several national groups took part in developing the NGSS and currently thirteen states and the District of Columbia have
adopted some form of the NGSS to serve as their science standards. In states that have not
officially adopted the NGSS, some individual districts have begun the process of adopting the
standards on their own, including the district that serves as the setting of this study. For districts
in both adopting and non-adopting states, meeting the demands of the Framework and the NGSS
will prove no easy task as they call for significant shifts to science education (Krajcik et al.,
2014; Penuel & Fishman, 2012).

Perhaps the most significant shift called for in the Framework and the NGSS centers on
developing students’ proficiency with “three-dimensional science learning” (National Research
Council, 2012). Three-dimensional science learning calls for the integration of disciplinary core
ideas, science and engineering practices, and crosscutting concepts into a cohesive and
meaningful experience for students (National Research Council, 2012, 2014a). This form of
learning foregrounds how knowledge in science and the means by which such knowledge are
achieved are inseparable from one another and that a unity to science exists across disciplinary
subfields. Krajcik et al. (2014) provide a rationale for an integrated approach to science
education along these lines:

If we want students to learn the content, they have to engage in the practice. But if
we want students to learn the science and engineering practice, then they have to
engage in content. Leave one out, and students will not develop proficiency in the
other (p.159).

In essence, three-dimensional science learning demands a qualitatively different
experience for students from much of the current practice in science education. In many
classrooms, students learn disciplinary core ideas as “facts-in-isolation” and come to know the
practices as components within a linear scientific method (Bacolor et al., 2015; Bell et al., 2012;
Eisenhart et al., 1996; National Research Council, 2012). The purposeful integration of science and engineering practices, disciplinary core ideas, and crosscutting concepts, demands that students more authentically engage in the sort of knowledge-building characteristic of real scientists and engineers and how they develop scientific and engineering knowledge in their activity (National Research Council, 2012).

A key mechanism of achieving three-dimensional science learning is engagement with science and engineering practices. The Framework describes science practices as those that scientists employ as they investigate and build models and theories about the world, and engineering practices as those engineers use as they design and build systems (National Research Council, 2012). The use of science and engineering practices allows for the realization of three-dimensional science learning as all science learning should involve engaging in practices to build and use knowledge (Reiser, 2013). Specifically, students should engage in science and engineering practices to build pieces of disciplinary core ideas and connections to crosscutting concepts (Reiser, 2014). In addition, students should develop the capacity over time to use the practices together or in isolation as needed (National Research Council, 2012), reflecting views that the science and engineering practices interrelate “as an unfolding and often overlapping sequence, or a cascade” (Bell et al., 2012, p. 18).

Professional development will play a key role in supporting teachers to meet the demands of the NGSS (Penuel & Fishman, 2012; Wilson, 2013), including understanding how to productively support students in the practice of modeling. Providing quality professional development to the myriad contexts of large numbers of teachers presents a daunting challenge (Wilson, 2013). Much of the challenge of achieving gains from professional development centers around the implementation setting of the professional development (Penuel & Fishman, 2012).
Effective professional development must attend to the varied settings of districts and schools (National Research Council, 2012) and seek to provide specific training to help teachers address the concerns of their classroom (Oliveira, 2010). Typically, however, professional development focuses on isolated skills and techniques, presenting teachers with a “carnival of options” (Wilson, 2013, p. 310). Promoting isolated approaches in this way does not cohere with the integrated vision for science education put forth by the *Framework* (National Research Council, 2012). Further complicating efforts to effectively prepare teachers for implementing the NGSS, professional development for science instruction in general remains scarce (Wilson, 2013).

Professional development that will prepare teachers to implement the NGSS will have to address, ideally in an integrative manner, the shifts called for in the *Framework* (National Research Council, 2012). Reflective of the shift towards three-dimensional science learning (National Research Council, 2012, 2014a), professional development should provide teachers with opportunities to plan and implement instructional strategies that productively engage students in science and engineering practices—such as developing and using models—in the pursuit of building understanding of disciplinary core ideas and crosscutting concepts. Providing teachers with time to plan and implement instructional strategies that integrate science and engineering practices as part of professional development can support teachers in engaging students in those practices, including using models (e.g., Schwarz and Gwekwerere, 2007), posing questions (e.g., Harris, Phillips, & Penuel, 2012), engaging in argumentation (e.g., Osborne, Erduran, & Simon, 2004; Simon, Erduran, & Osborne, 2006), and constructing explanations (e.g., McNeill, 2009). Relatedly, professional development should model the instructional shifts called for in the NGSS and provide portable curricular tools for teachers to adapt and implement in their classroom. Curricula and instructional tools that embody the vision
of three-dimensional science learning can productively support shifts in teachers’ instruction (Davis & Krajcik, 2005; McNeill, 2009).

LITERATURE REVIEW: DEVELOPING AND USING MODELS IN SCIENCE CLASSROOMS

The practice of developing and using models has a central role in the development of scientific knowledge and scientific literacy. In investigating phenomena, scientists create and use models in order to represent complex systems associated with phenomena (National Research Council, 2012). However, as famously stated by renowned statistician George E. P. Box (1979), “All models are wrong but some are useful” (p. 2). Taking up the “wrongness” aspect of Box’s axiom, models realistically, and oftentimes purposefully, do not perfectly represent a phenomenon. Instead, modeling requires a self-conscious disambiguation between the model and its referent (Lehrer & Schauble, 2000). Importantly, the models themselves become objectified tools. As such, they can serve as the focus of revision in light of new data and be made to bring into focus certain aspects of a complex phenomenon for study. Taking up the “usefulness” aspect of Box’s axiom, a scientific model serves as a representation, one that abstracts and simplifies a system in order to productively support the development of explanations and predictions of scientific phenomena (Schwarz et al., 2009). These explanations and predictions can then undergo scrutiny within the scientific community, perhaps contributing to our collective scientific understanding of a phenomenon. Models that support productive reasoning to facilitate the generation of explanations and predictions about a phenomenon can take many forms, from physical models like a model of the solar system, to representational models like diagrams, to syntactic models using analogy, to hypothetical-deductive models like the model of an atom that rely on unseen properties (Lehrer & Schauble, 2000).
The vision for science education as delineated in the *Framework* calls for students to gain a grasp of how to develop and use models to represent systems, explain phenomena, and make predictions (National Research Council, 2012). The level to which students can effectively engage in the practice of modeling will change over time, theoretically following a learning progression, with students’ conceptions of modeling moving from basic to more complex (Schwarz et al., 2009). Although children naturally show a predilection to engaging in basic forms of modeling (Lehrer & Schauble, 2000), achieving the idealized end goal of having students authentically engage in complex modeling in ways akin to the activity of practicing scientists and engineers brings into relief the need for instructional approaches that support students’ development of their capacity to engage in modeling (Lehrer & Schauble, 2000).

Instruction to support students’ capacity to engage in the practice of developing and using models should ideally develop students’ sense of science as a continual knowledge-building enterprise (National Research Council, 2012). Instruction should make explicit how a scientific model serves as a tool (Van Driel & Verloop, 2002) and as a means to support reasoning about how a phenomenon occurs (Lehrer & Schauble, 2000). Following the vision for three-dimensional science learning, students should engage in modeling as a means to facilitate the active construction of knowledge or what the *Framework* would refer to as a disciplinary core idea of crosscutting concept. In this process of actively constructing knowledge, instruction should highlight the iterative nature of modeling (Van Driel & Verloop, 2002), that is, the fact that models change in light of new evidence and that alternative competing models may exist for a phenomenon (Lehrer & Schauble, 2000). In doing so, models no longer become seen as inert representations of a collection of science facts (Van Driel & Verloop, 2002); instead, their dynamic nature underscores how scientific knowledge remains in flux (National Research
Council, 2012). In part, this dynamism results from how models—even long-held models—will fundamentally remain incomplete representations of reality (Lehrer & Schauble, 2000). Emphasizing how models always represent an incomplete representation provides students with more opportunities to understand science as a continual knowledge-building enterprise, seeking to iterate on models (Van Driel & Verloop, 2002). Importantly, instruction should make explicit that despite the limitations of models and modeling, models have utility in that they come from evidence observed in the natural world and can provide means to engage with problems in the world (National Research Council, 2012).

Productively engaging students in the practice of modeling has generally proven difficult for science teachers. The problem appears to have two related dimensions. First, teachers’ conceptions of what constitutes a model differ from scientists’. Although science teachers may have a general definition of a model, they will likely not have a significant knowledge of models and modeling in science and will have varied understandings of what criteria constitutes a scientific model (Van Driel & Verloop, 1999). Relatedly, teachers may not understand the purpose of modeling in science and criteria for engaging in modeling (Justi & Gilbert, 2002). Second, teachers may not have developed the pedagogical content knowledge (Shulman, 1987; Van Driel, Veal, & Janssen, 2001) necessary to engage students in productive modeling. Additionally, teachers knowledge of how their students’ conceive of models and their students’ modeling abilities may prove limited (Van Driel & Verloop, 2002). In order to effectively support students’ capacity to productively engage in modeling over time, teachers must have an appropriate understanding of modeling themselves (Justi & Gilbert, 2002). The limited opportunities teachers provide to students to productively engage in modeling, in part, likely stems from a lack of specific support for teachers in terms of teacher development.
CONCEPTUAL FRAMEWORK

The analysis of this study will utilize sociocultural theory as its overarching conceptual framework. Sociocultural theory comes primarily from the work of Lev S. Vygotsky. A central tenet of sociocultural theory is the idea of cultural mediation. In his seminal work, *Mind in Society* (1978), Vygotsky introduced his notion of cultural mediation, the use of cultural artifacts as an “auxiliary means” (p.52) for shaping individuals’ actions and experiences in the world. Vygotsky posited how cultural artifacts, namely psychological tools but physical tools as well, mediate unique human thought, or our higher psychological processes (Cole & Wertsch, 1996; Vygotsky, 1978).

Wertsch (1991, 1994) further developed Vygotsky’s ideas about mediation, focusing on the study of mediated action. The study of mediated action is the study of how people take up or appropriate tools in goal-directed action. Given this study’s emphasis on how teachers take up tools from the NGSX to support engagement in the practice of developing and using models, we analyze teachers’ uptake of tools as forms of mediated action in the professional development setting and in their classrooms. A mediated action analysis draws our attention specifically to describing the specific actions in which teachers use tools to support their activity and their purposes for doing so (Wertsch, 1991, 1998).

Of particular importance for understanding teacher learning is how teachers’ appropriate cultural tools from the professional development context in the classroom. Such appropriation is one way to reframe a basic aim of professional development in sociocultural terms, namely to impact classroom practice. But tools sometimes travel back from the classroom and are taken up in professional development events subsequent to the initial professional development. Kazemi and Hubbard (2008) propose a sociocultural approach to studying mediated action that takes this...
potential for multi-directionality of appropriation as a starting point for a theory of teacher learning that unfolds across multiple activity settings.

Kazemi and Hubbard (2008) contend that teachers’ participation within these different settings “coevolves” to influence teacher learning over time. The linkages between settings occur via “boundary objects” (Star & Griesemer, 1989) in the form of the tools that travel back and forth from the professional development and classroom settings. Teachers, however, will use knowledge or tools for different purposes in different “mediating context[s]” (Kazemi & Hubbard, 2008, p. 429). For example, while a tool may have had the purpose of mediating teacher learning during the professional development, in the classroom it may serve to mediate student learning. The tool then may again serve to mediate teacher learning in the professional development. In this way, a coevolution of participation occurs: teachers’ use of the tool in one setting influences their participation in the other. In inhabiting multiple activity settings, teachers must act as “brokers” (Wenger, 1998), reconciling the different meanings the tools have in these different contexts in order to build an overall understanding of the use of the tools in practice (Kazemi & Hubbard, 2008). In some cases, this reconciliation leads to teacher learning that facilitates changes to classroom practice. The Kazemi and Hubbard (2008) framework calls on us to pay careful attention to how teachers make meaning and use of tools from professional development in the classroom, as well as whether and how they bring tools and meanings from the classroom into the professional development setting.

THE CURRENT STUDY

This study is a cross-setting case study and utilizes aspects of ethnographic qualitative research methodology (Emerson et al., 1995b). Cross-setting studies examine learning across different settings and principally employ ethnographic methodologies (Penuel & Frank, 2014). In
this instance, how teachers learn about the NGSS and the practice of developing and using models serves as the phenomenon of interest, one that occurs over two settings: (1) NGSX professional development setting and (2) Participating teachers’ classrooms. Ethnographic qualitative methodology specializes in capturing individuals’ activity in a setting, primarily through field notes, and seeks to construct a “thematic narrative” (Emerson et al., 1995b, p. 170) of participants’ experiences. Such an approach fits well with this study’s aims of constructing an interpretation of how the various practitioners’ understandings of the practice of developing and using models developed across settings, both through their participation in activities within the NGSX professional development and through their adaptation and implementation of NGSX tools and ideas in their classrooms. Ethnographic qualitative methodology, importantly, provides a means to develop narratives of each focus subject. This allows for an analysis into expected variances in teachers’ understanding of the practice of modeling.

Researchers occasionally participated in a professional development activity alongside participants, such as through supporting teachers with collecting data on their implementation of NGSX tools within their own classrooms, answering questions related to the NGSS during professional development sessions, or supporting the implementation of the NGSX more generally as requested by district administrator partners. Such instances fit within the role of a peripheral participant observer, an orientation coherent with collecting ethnographic data (Spradley, 1980). Participant observer data can prove particularly useful in building an emic perspective within the data (Maxwell, 2012), a perspective on activity from the point of view of participants, in this case, specific to participants’ engagement with different aspects of NGSX activity within the professional development setting and within teachers’ own classrooms.
Participants in the Study

A total of thirty participants took part in this study. These participants included five district administrators from the district curriculum office, the authors of this study who researched the NGSX, and twenty-one school educators who engaged with the NGSX. Of the twenty-one educators, seven worked within elementary schools and the remaining fourteen worked within secondary schools. Six of the elementary educators worked as teachers and one worked as an administrator. Among the secondary school educators, thirteen worked as teachers, with one having a dual role as a science coach, and one educator did not teach but served as a teacher evaluator. The secondary school teachers varied in the subjects they taught from 6th, 7th, and 8th grade middle school science, to high school subjects such as biology, chemistry, physics, earth science, and astronomy. All educators participating in the PD agreed to be participants in the study. Practitioners self-selected into the NGSX professional development in response to a recruitment process completed by district administrators.

Researchers recruited two elementary practitioners and six secondary practitioners to serve as focus participants. These focus teachers had the most consistent attendance of participants, the prime factor in their selection. The focus sample included two male secondary science teachers, four female secondary science teachers, and two female elementary level teachers—one a classroom teacher, the other a teacher in a semi-administrative role. Accordingly, with their role as focus participants, these teachers underwent additional, more intensive data collection protocols (e.g. interviews, classroom observations) beyond those used with general participants.
The Professional Development Intervention: NGSX

The NGSX system uses a “hybrid” approach of web-based and in-person activities, seeking to capitalize on each format’s unique affordances (Moon, Passmore, Reiser, & Michaels, 2013). During in-person professional development sessions, led by local facilitators, teachers actively engage with science content through hands-on challenges and collectively attempt to make sense of presented phenomena in small and whole groups. Regularly posting online reflections or participating in online polls among other web-based activities occurs during in-person sessions, often with the option for teachers to complete such activities on their own time (Moon et al., 2013). In addition, the NGSX system has participants analyze rich video cases of exemplar science classrooms engaged in trying out complex teaching practices (Moon et al., 2013). Discussion of activities and videos occurs in small and whole group formats and routinely follows scripted prompts provided to facilitators by the NGSX designers. These principled discussions index the broader aims of the NGSX to embed expertise within the system and not within a particular individual (Moon et al., 2013). Other examples of embedding expertise within the system include the use of instructional videos where the NGSX designers themselves introduce phenomena for exploration, model the use of science and engineering practices in seeking to explain phenomena, and provide context for the use of science and engineering practices.

A major goal of the NGSX centers on developing teachers’ capacity to productively engage students in science and engineering practices, such as engaging in argument from evidence, constructing explanations, and developing and using models (Moon et al., 2013). The majority of sessions examined in this study have participants engage in science and engineering practices to develop and refine models that can explain phenomena related to air pressure, with
participants utilizing an “air puppies” model introduced by the NGSX designers. Exemplifying a commitment to coherence between the substance of the professional development and teachers’ own practices, the NGSX system also has teachers complete “On Your Own” assignments where they implement tools introduced during NGSX sessions in their classrooms with students. The designers of the NGSX intended for these tools to support students in engaging in science and engineering practices.

One set of tools—public representations—supports students in collectively organizing their thinking over time while investigating a phenomenon. For example, while investigating a phenomenon, students can add ideas to an explanation checklist that they see as essential for a final explanation. Students can also use a public summary table to hold and revise their ideas over time in response to new evidence or arguments in order to create a robust model of a phenomenon. In addition, students can use sticky notes to organize possible revisions to a model or language scaffolds to facilitate more productive comments while developing models. Besides public representations, the NGSX calls for teachers to implement talk moves—defined as verbal strategies to help students learn how to explain their own reasoning to others and build on the thinking of others (National Research Council, 2014b)—in their classrooms. Examples of talk moves include having students add to others’ thinking (e.g. “Can anyone take that suggestion and push it a little further?”) or asking students for evidence or reasoning (e.g. “Why do you think that?”) (Michaels & Connor, 2012).

Data Collection and Procedures

Researchers collected all data for this study during the district’s implementation of the NGSX professional development from January 2014 to February 2015. Table 1 shows an inventory of the five sources of data collected and their correspondence to research questions.
Table 1

Inventory of data collected and alignment to research questions

<table>
<thead>
<tr>
<th></th>
<th>RQ 1 (Effect of NGSX PD)</th>
<th>RQ 2 (Effect of classroom)</th>
<th>RQ 3 (Effect of facilitation)</th>
<th>Data Inventory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observations of NGSX PD</td>
<td>X</td>
<td></td>
<td></td>
<td>9 sessions</td>
</tr>
<tr>
<td>sessions</td>
<td></td>
<td>X</td>
<td></td>
<td>Video (8)</td>
</tr>
<tr>
<td>Observations of classroom</td>
<td></td>
<td>X</td>
<td></td>
<td>Audio (1)</td>
</tr>
<tr>
<td>teaching</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participant Interviews</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>8 interviews</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Audio (8)</td>
</tr>
<tr>
<td>Participant Surveys</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>5 surveys</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(64 responses)</td>
</tr>
<tr>
<td>Collected Artifacts</td>
<td>X</td>
<td>X</td>
<td>60+ items</td>
<td>Digital (50+)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Physical (&lt;10)</td>
</tr>
</tbody>
</table>

**Observational data of NGSX professional development sessions.** Researchers video or audio recorded each NGSX PD session and created fieldnotes from the original media and notes taken during the session. When developing field notes, we attended to and documented: (1) topics discussed in each study group session, (2) how participants engage with the activities and tools provided within each session, and (3) any statements about plans regarding whether and how to implement NGSX tools or ideas. Data collected during these sessions informs the ways in which the NGSX structure, the activities and tools embedded within it, and the facilitation of the PD mediate teacher learning about the practice of developing and using models. Accordingly, analysis of these sources of data contributed most directly to research questions 1 and 3.

**Observational data of classroom teaching practices.** Researchers visited the classrooms of volunteer focus teachers to understand how teachers implemented ideas and tools
from the NGSS in their classrooms. Only focus teachers, those participants who showed consistent attendance and agreed to more intensive data collection procedures, had their classroom observed. These observations occurred in conjunction with NGSX “On Your Own” assignments that required teachers to implement specific tools from the NGSX in their classrooms. Teachers recorded, either via video or audio, their implementation of these tools and practices in their classroom. Researchers either assisted with recording these implementation efforts, receiving a media copy of the observation at that time, or received copies of teachers’ media afterwards. Researchers created fieldnotes during in-person observations. Focal topics for fieldnotes included: (1) which of the eight NGSS practices do teachers engage students in and how do they support students’ participation in those practices, with a particular interest in modeling, (2) what content knowledge is the target of instruction and how it relates to the core ideas in NGSS, (3) if and how practices and content knowledge are integrated, and (4) in what ways did the tools and activities adapted by the teacher for their classroom mediate student learning. Researchers did not use a structured observation protocol since appropriate structured protocols aligned to NGSS do not yet exist in the field. Since this data focuses on the implementation of NGSX activities and tools within teachers’ classrooms, analysis of this data corresponded most directly to answering research question 2.

**Interviews.** Interviews with focus teacher participants occurred either over the phone or via an online video conferencing program. Researchers made verbatim transcriptions of the audio recordings. The interviews followed a structured protocol. Protocol topics included: (1) teachers’ ideas about developing and using models in science, (2) teachers’ use of ideas and tools from the professional development in adapting or designing instructional materials, (3) issues or concerns that prompted individual or collective learning about the NGSS, (4) perceptions of the
gap between current and NGSS-aligned practice, and (5) plans to implement instruction aligned to NGSS. These interviews occurred at the conclusion of the NGSX professional development implementation within the district. This data provides a focused examination of teachers’ conceptions of the practice of modeling, how the NGSX system and facilitators mediated such understandings, and how teachers utilized their understandings and tools from the NGSX in attempts to shift their classroom instruction to more align with the NGSS. As such, analysis of this data supported answering research questions 1, 2, and 3. See Appendix C to examine the teacher interview protocols employed.

**Surveys.** All teachers participating in the professional development completed surveys designed by the NGSX designers, both before the implementation began and after it finished. The survey assessed their understanding of the NGSX content and asked questions about their teaching practices (e.g., how well prepared they feel they are to assess student thinking or support classroom discussion). This data provided a sense of teachers’ understanding of the NGSS and its associated practices, such as modeling, as well as a sense of their classroom practices prior to participation in the NGSX professional development. Comparing this data to that collected during the exit survey allowed researchers to gain insights as to the degree teachers felt their understanding of the NGSS and the practice of developing and using models grew and to what degree they accordingly shifted their classroom practices. In addition, researchers developed and administered a short mid-process survey. This survey called for teachers to reflect on their experiences in the NGSX up to that point, including the effectiveness of facilitation, and on their opinions for bringing the NGSX to other teachers within the district. Insights from these surveys supported answering research questions 1, 2, and 3. See Appendix C to examine the teacher surveys employed.
Artifacts. During each NGSX PD session as well as activities outside of the PD sessions, teachers created artifacts that relate to their understanding of the NGSS as well as artifacts that serve as reflections on their teaching practices and attempts to engage their students in modeling. Researchers collected physical artifacts, such as student work samples, primarily through digital photos. Other artifacts collected included mostly digital artifacts. For example, the NGSX website served as an important tool to organize activity during professional development sessions. Researchers received a spreadsheet from the NGSX designers with all entries participants’ made on the NGSX website, such as reflections and polling data. Researchers also collected e-mails from facilitators and participants regarding the NGSX implementation. As artifacts came from multiple activity settings—the professional development setting, the classroom setting, and perhaps others—analysis of this data contributed to answering both research questions 1 and 2.

Approach to Analysis

Development of initial coding scheme. In order to address this study’s research questions, all sources of data mentioned above, once transcribed into text, underwent successive rounds of data analysis featuring a mix of deductive, theoretically driven coding and inductive, bottom-up coding primarily to reduce the data and discern productive patterns (Emerson et al., 1995a). Deductive approaches have the researcher fit data into “already established categories” (Emerson et al., 1995a, p. 151). Inductive approaches, on the other hand, have researchers put more emphasis on “developing rather than verifying analytic propositions” (Emerson et al., 1995a, p. 143).

In this study, researchers utilized a deductive approach to establish coding bins that incorporated the conceptual framework elements of the study design. Specifically, researchers
developed coding bins that reflected the components of sociocultural theory—with an emphasis on mediated action—and that most align to the research questions explored. The primacy of mediated action within this study’s sociocultural conceptual framework aligned with the study’s concerns for understanding how teachers engaged in activity, what tools the NGSX provided to mediate teacher learning of the NGSS and modeling, and how these tools manifested within the classroom to mediate student learning. Accordingly, researchers created high-level parent codes for *Individuals* and *Mediation Means*. The individuals bin included child codes for the anonymized names of all participants in the study engaging in activity in order to trace individual learning across activities. The mediational means bin included prominent forms of mediation utilized by participants such as elements of the NGSS (e.g. *Science and Engineering Practices*) and tools from the NGSX (e.g. *Specific Models, Videos, and Labs*). Researchers sought to find co-occurrences of codes across the bins *individuals* and *mediational means* to provide insight into what NGSX tools participants did or did not take up.

In terms of the framework provided by Kazemi and Hubbard (2008), we created a parent bin for *Activity Settings* to reflect their framework’s emphasis on the multidirectional influences on teacher learning from multiple settings. This study included child codes for the main activity settings teachers traversed, chiefly the classroom and NGSX professional development settings. Use of these codes supported analysis of how NGSX activities and tools mediated teacher learning across the NGSX professional development setting and classroom setting. These codes allowed, for example, a means to trace the usage of tools as mediators between settings and how teachers brokered meaning between different settings.

The creation of additional codes, both parent and child, resulted from our use of a more inductive approach (Emerson et al., 1995a, p. 143). Researchers examined data without thought
to preconceived categories and instead sought to discern additional codes and coding categories, as well as additional questions, from reading the data. A review of the data allowed for parent codes to arise inductively, notably a category for *Types and Levels of Uptake*, which housed child codes describing the manner in which tools moved from the NGSX to teachers’ classroom settings and the level at which participants took up these tools. Child codes for types of uptake that arose from the data included *Prompted Take-Up*, for activity and talk relating to the “On Your Own” tasks teachers completed to integrate tools from the NGSX in their classrooms, and *Unprompted Take-Up*, where participants used tools from the NGSX in their classrooms with no specific prompting. To capture a sense of the level to which participants took up tools and ideas presented in the NGSX, researchers created codes ranging from *Subscribing* to tools through wholly positive talk, to a mix of positive and negative talk about tools constituting *Partial Take-Up*, to wholly negative talk or rejection of tools denoting *Failed Take-Up*. Researchers inductive approach also led to the creation of the code *Effect of Facilitation*, which sought to capture how local facilitation of the NGSX influenced participants’ experiences, as well as additional child codes for coding categories established from deductive approaches such as child codes under mediational means (e.g. *Public Representations* and *Talk Moves*).

**Finalizing and applying coding scheme.** Before applying the coding scheme to all data, researchers sought to measure the reliability of the initial coding scheme and revise it if necessary. Members of the research team completed an inter-rater reliability test wherein a pair of researchers coded data excerpts from a subset of the larger dataset. This test resulted in a Cohen’s kappa coefficient statistic for each code (Cohen, 1960). In order to interpret the level of agreement for the resulting Cohen’s kappa values, researchers applied the recommendations of Landis and Koch (1977, p.165) who suggested the following interpretations for a kappa statistic.
value: less than 0.0 – Poor Agreement; 0.00 to 0.20 - Slight Agreement; 0.21 to 0.40 – Fair Agreement; 0.41 to 0.60 – Moderate Agreement; 0.61 to 0.80 – Substantial Agreement; 0.81 to 1.00 – Almost Perfect Agreement. Codes with a Cohen’s kappa coefficient value that fell below 0.5 were deemed problematic and removed from the coding scheme. To determine the overall reliability between the pair of raters for the revised coding scheme, researchers calculated a pooled kappa statistic across all remaining test codes (De Vries, Elliott, Kanouse, & Teleki, 2008). The resulting pooled kappa value of 0.70, as interpreted by Landis and Koch (1977), indicated a substantial amount of agreement between raters for the overall coding scheme.

Having obtained a satisfactory level of inter-rater reliability for the final coding scheme, a rater from the test pair then applied the coding scheme to all data.

**Selection and analysis of excerpts.** The application of the coding scheme identified excerpts demonstrating patterns of activity that routinely emerged from our body of data. In addition, the application of the coding scheme identified anomalous excerpts that did not hold to previously established patterns. Researchers sought to move from holistic levels of interpretation across the dataset to more explicit levels of interpretation for each excerpt, which in turn can inform the development of new holistic levels of meaning. Accordingly, excerpts researchers identified as representative of routine or anomalous patterns underwent meaning reconstruction (Carspecken, 1996). This process included deriving possible meaning fields (i.e. possible meanings for each excerpt) through the balanced use of emic and etic perspectives (Maxwell, 2012), as well as through comparing an activity to similar activities, and through examining the contiguity of participants’ actions as part of a sequence or activity. Researchers also explored higher level meaning fields, utilizing paradigmatic horizon analysis (Carspecken, 1996). Specifically, researchers applied temporal horizon meaning fields to judge how the timing of an
activity could give meaning to an excerpt. Researchers also applied paradigmatic horizon meaning fields in order to consider how contextual or background elements, particularly the social or interactional context of an activity, could provide meaning to an excerpt. Upon completion of this analysis, researchers then sought to create a cohesive narrative of findings.

**Selection of participants for case studies.** The application of a coding scheme informed the decision of which focus participants should serve as illustrative case studies. Results from coding provided different patterns of activity for each focus participant. Given that fieldnotes of NGSX sessions routinely focused on the discourse and actions of only a subset of focus participants which may artificially inflate the sense of those participants’ activity, examination of the code counts for each participants’ structured interview—an activity all participants completed—provided a more even and adequate basis for comparing participants’ experiences. After considering patterns of counts for codes that align to this study’s focus of examining how the NGSX may support teachers’ understanding of developing and using models—specifically, codes within *NGSX Tools* and *types and levels of uptake* as well as the code *modeling*—researchers selected Jane and James to serve as case studies. Their patterns of data indicated contrasting experiences in regards to how they engaged with the NGSX to support their understanding of the practice of developing and using models. Jane showed high counts for the aforementioned codes, which suggested a high uptake of the tools and ideas put forth in the NGSX around modeling as envisioned in the NGSS. Alternatively, James showed low counts for the aforementioned codes, which suggested less uptake of the tools and ideas from the NGSX.

**RESULTS**

Below, we develop four major claims which directly inform the research questions posed in this study. For all claims, we first provide high-level findings in the form of confirming or
disconfirming patterns of evidence drawn from across various teachers’ experiences with the NGSX. In addition, for the last two of these four claims, we further illustrate and substantiate these findings by presenting case studies highlighting relevant experiences from two selected focus teachers. The central claims we put forth are as follows:

1. Among the practices emphasized in the NGSX, teachers oriented primarily to the practice of developing and using models and secondarily to other practices emphasized in the NGSX. Participants differed in both the degree to which they oriented to the practices and which practices, after modeling, they oriented to. This suggests that teachers may have differed from one another in how they engaged in understanding these practices.

2. The facilitation of the NGSX by local administrators led to mixed results in regards to supporting teacher learning. Mismanagement of logistics and comments that estranged elementary school teachers led to high attrition of participants. However, fidelity to individual session designs and skilled facilitation around talk moves and public representations may have contributed to better uptake of those particular tools among the participants that remained.

3. The sequence of investigations and the building of specific models, interleaved with discussion activities and video presentations, helped build teachers’ understanding of developing and using models. Some teachers moved from conceptualizing models as a static representation to a representation that could explain a phenomenon and that could be revised over time. However, aspects of some teachers’ understanding of modeling did not change significantly.

4. The largest uptake of tools from the NGSX by teachers for their classrooms occurred with talk moves, public representations, and specific models from the NGSX. Teachers
used these tools largely “as is” to fit within a range of content. Some teachers used these tools to support their students in modeling activities and brought their experiences of using these tools in their classrooms back to subsequent NGSX sessions to provide further learning opportunities.

The focus teachers that serve as the subject of the case studies presented in this section include Jane and James. During this study, Jane was a fourth-year high school science teacher who taught primarily chemistry, physics, and earth/space science. Over 85% of the students at Jane’s school received free or reduced price lunch, an indicator of poverty. James was a 7th and 8th grade middle school science teacher with twenty-five years of teaching experience. James taught at a K-8 school where over 90% of students received free or reduced price lunch.

**Claim 1: Teachers Oriented to the Practice of Developing and Using Models**

A key aim of the NGSX revolved around the development of teachers’ capacity to engage their students in the use of science and engineering practices as called for in the NGSS. In particular, the designers of the NGSX sought to support teachers’ understanding of the practices engaging in argument from evidence, constructing explanations and designing solutions, and developing and using models (Moon et al., 2013). Focus teacher participants, as a group and individually, primarily orientated to the practice of developing and using models before orientating to the other practices emphasized in the NGSX, such as engaging in argument from evidence and constructing explanations and designing solutions. Focus teachers differed in which actual practices they oriented to after the practice of modeling and also varied in the degree to which they oriented to all practices examined, which suggests teachers may have had different levels of engagement in how they developed an understanding of these practices.
Patterns of teachers’ orientations to practices. Examining how teachers oriented to different practices emphasized in the NGSX, such as developing and using models, involved identifying and interpreting patterns that resulted from the application of the coding scheme.

Specifically, researchers examined counts where a researcher applied a code for a science and engineering practice to an excerpt of data while also applying a code for a particular participant (see Table 2). As alluded to previously in the methods section, fieldnotes focused on sub-sets of participants and coding these excerpts inflated the amount of perceived activity for certain participants. Although code counts across all data sources provided some insights into participants’ experiences, to provide a more even comparison of participants’ experiences in the NGSX, we focused mainly on code counts from the structured interviews which researchers uniformly administered to all participants.

Table 2

References to science and engineering practices made by focus participants

<table>
<thead>
<tr>
<th>Practices</th>
<th>AndreaE</th>
<th>AlexisE</th>
<th>ChrystalM</th>
<th>ElizabethM</th>
<th>JamesM</th>
<th>StephanieM</th>
<th>JaneH</th>
<th>MichaelH</th>
</tr>
</thead>
</table>

NOTE: Interview data in bold. All data in brackets. “E” = elementary teacher, “M” = middle school teacher, and “H” = high school teacher.

Examination of code counts for focus participants from the structured interview data showed a consistent pattern of participants primarily orienting to the practice of developing and using models. Participants as a group made more references to the practice of developing and using models (105 total references) than the practices of constructing explanations and designing solutions and engaging in argument from evidence (25 and 10 total references respectively).

Additionally, examining each individual focus participants’ code counts further supports the
assertion that participants oriented primarily to the practice of developing and using models. Of the eight focus participants, the practice of developing and using models had the highest occurrences for all eight participants. High counts for the practice of developing and using models across all participants suggests participants may have engaged in understanding modeling more so than other practices. Of note, only three questions, corresponding to three data excerpts, explicitly prompted teachers to discuss their experiences with modeling. With their counts for the code *modeling* above three instances, all participants referenced modeling in other excerpts unprompted. Only one interview question prompted teachers to discuss practices other than developing and using models, but with generally low counts for these other practices, teachers still made more unprompted references to developing and using models.

Comparing the code counts for science and engineering practices between the focus participants provided a sense of the degree to which focus teachers oriented to each practice in relation to one another. Looking at the code counts for the code *modeling* across participants’ structured interviews, researchers observed wide variation in participants’ responses. Jane led all participants with twenty references to modeling, more than double the number of references made to modeling by James. This variation indicates that some teachers oriented more strongly to the practice of developing and using models than other teachers, suggesting some teachers engaged in understanding this practice more than other teachers.

Examination of code counts between teachers for the *explanation* and *argumentation* also revealed notable variation. For most participants, the practice of constructing explanations and designing solutions received the second most references after the practice of developing and using models. However, James, Chrystal, and Elizabeth each made more references to the practice of engaging in argument from evidence over constructing explanations. Also, while
Jane, Chrystal, and Elizabeth all made references to both practices, other teachers made references to only one of these practices. This variation in terms of which of these two practices participants referenced most and which practices they actually referenced, indicates teachers oriented to these practices quite differently, which suggests teachers had differing levels of engagement in understanding these practices.

Claim 2: Influence of Local Facilitation on Teacher Learning

One focus of this study sought to examine how local facilitators’ implementation of the NGSX supported or hindered teachers’ in building their understanding of the practice of modeling and the NGSS. The local facilitation of the NGSX carried out by administrators from the district’s central office resulted in a mix of effects. On the one hand, local facilitators’ handling of the logistics for the NGSX, notably the inability to secure funding for teachers’ pay to attend the sessions and difficulty scheduling NGSX sessions in a consistent and timely manner lessened some teachers’ desire to participate in the PD. Also, comments made by the facilitators led elementary school teachers to feel they did not have the same amount of respect afforded them as secondary school teachers. On the other hand, the facilitators, by and large, showed integrity to the design of the NGSX sessions, and their facilitation of elements such as talk moves aligned closely with the intent of NGSX. Relatedly, facilitators demonstrated further integrity in their implementation by creating additional opportunities for teachers to build their understanding of how to engage students in the practice of modeling by providing a small forum for teachers to share their classroom experiences of using tools from the NGSX with other colleagues. We take up each of these elements, drawing on experiences across practitioners, in more detail below.
Logistical management by local facilitators undermined teachers’ participation.

During the recruitment of teachers to participate in the NGSX, district administrators had promised teachers additional pay for their time to attend the PD. Unfortunately, due to a misunderstanding with a local foundation about funding, the facilitators later had to renege on this promise which seemed to lessen some teachers’ motivation to continue in the PD. Midway through the process, for example, teachers began to openly question the ability of the administrators to compensate them. Prior to leaving for summer break, Chad, the main facilitator asked for participants to complete a series of “On Your Own” assignments from the NGSX. A teacher responded with an open e-mail to Chad and purposefully copied all other practitioner participants on the message:

Hi Chad and NGSXers,

Thanks for the summary of summer work to do. I wouldn't have it on my radar otherwise.

For the benefit of everyone, I am wondering how much time the 3 tasks will take (except the survey) and if there will be compensation provided for them. Perhaps for an extra 3-hour "independent study" NGSX PD session?

Just putting it out there... (High School Teacher, E-mail, 5/28/14)

Chad and the facilitators did not write a reply to the teacher and failed to acknowledge the concerns that this teacher was “putting out there.” Subsequently, this teacher, who felt she was speaking for many other participants, did not continue her participation in the NGSX when sessions resumed.

In addition to issues of compensation, an extended break that occurred in the middle of the implementation of the NGSX pathway proved detrimental to teachers’ participation. After
district administrators had facilitated the initial four sessions of the NGSX on a regular monthly basis as planned and negotiated between the district and the NGSX designers, the final three sessions did not occur until six months later in the following school year. Focus teachers who remained in the PD surmised that this led some participants to lose motivation for the NGSX process. One focus teacher, Andrea, offered the following in an interview in response to a prompt of what she found least helpful about the NGSX in supporting learning about the NGSS:

I guess I might just say the timing and that might simply be because it was stopped. You know? Like last year we really dug in and it seemed like we were kind of on a roll, and then summer hit and then it was a big lull. You know what I mean? So that was, I guess that was kind of tricky. […] But that part was hard, I guess. And then the group that we had last year was like twenty some-odd people and this year was four or five, you know? (Andrea, Interview)

Andrea seems to suggest that the timing of the sessions implemented by the facilitators had a negative effect on teachers’ participation in the PD. Indeed, her account of a high attrition rate among PD participants is consistent with attendance records for the PD sessions over time. Whereas initial sessions consistently saw at least twenty teachers in attendance, after the long hiatus, attendance dropped to eight teachers on a regular basis. The loss of participants greatly reduced opportunities for teacher learning from peers, or in the words of Andrea “It wasn’t as rich of a discussion and experience.”

Comments made by local facilitators alienated elementary school teacher participants. During an initial session not part of the official NGSX pathway but developed by the district facilitators, Chad, the lead facilitator made a comment that offended several of the elementary school practitioners: “An ‘a-ha’ that I just had that in sixth grade in in [this district]
that's the- if you're a kid that's the first time you've had a bona fide science teacher.” At the time Chad made the comment several elementary school practitioners voiced disbelief at his statement with an elementary school administrator offering, “It’s a little frustrating to hear you say that.” One elementary teacher who took particular umbrage with Chad’s comment wrote the following in a survey given halfway through the implementation of the NGSX:

I feel like right off the bat an off-handed remark about how real science doesn't start until middle school because elementary teachers don't really know science made me angry and I thought it was not a very professional statement to make! I happen to have a master’s degree in science and teach elementary grades, and my kids get great science! So I felt less valued than other members. (Elementary Teacher, Mid-Process Survey)

Chad’s “off-handed remark” proved to have a lasting impact on this and other elementary school teachers. All but two of the seven elementary level practitioners ceased their participation in the NGSX within the first four sessions. Follow-up attempts to interview elementary teachers to learn more of their experiences and why they left the PD proved unsuccessful and were ceased as called for in the study’s IRB protocol (i.e. not to place undue pressure on participants).

Results from the application of the coding scheme also provided further insights into how elementary school teachers experienced the facilitation of the NGSX by district administrators. Looking at the number of times focus participants referenced the facilitation of the NGSX in their structured interviews (coded as effect of facilitation), both elementary school practitioners, Andrea and Alexis, and also 6th grade teachers, Chrystal and Stephanie, referenced the facilitation of the NGSX more than focus participants from higher grades (i.e. 7th and above; see Table 3). This suggests elementary school teachers and 6th grade teachers may have responded more strongly to the facilitation of the NGSX than participants from higher grades. Examination
of the excerpts referencing the facilitation of the NGSX found elementary school practitioners made mostly negative critiques of the facilitation (e.g. “it might have been good too to have some times when we were together as elementary teachers to talk about it”). In contrast, the 6th grade teachers, as well as participants from higher grades, showed mostly praise for the facilitators (e.g. “I think Chad has played a role in that [guiding my understanding of NGSS] definitely”).

**Table 3**

*Focus participants’ references to the facilitation of the NGSX by district administrators*

<table>
<thead>
<tr>
<th>Practices</th>
<th>AndreaE</th>
<th>AlexisE</th>
<th>ChrystalM</th>
<th>ElizabethM</th>
<th>JamesM</th>
<th>StephanieM</th>
<th>JaneH</th>
<th>MichaelH</th>
</tr>
</thead>
</table>

*NOTE: Counts for interview data appear in bold. Counts across all data appear in brackets “[ ]”. Participants grade levels indicated by superscripts with “E” for elementary, “M” for middle school, and “H” for high school.*

**Facilitators’ fidelity to the design of the NGSX allowed teachers who stayed the full experience of the professional development pathway.** The NGSX calls for facilitators to follow a relatively set, principled format and facilitators, by and large, enacted the sessions as designed and did not get in the way of teachers’ learning. Indeed, when asked in interviews and surveys about the most effective aspects of the NGSX, no practitioner or focus teacher specifically cites the contributions of the local facilitators in enacting the NGSX sessions. Instead, quite consistently, participants cited prominent elements of the NGSX design—such as the labs, structured discussions, and videos—as beneficial to their learning. For example, one elementary teacher, Alexis, provided a typical response of what she found most helpful in learning about the NGSS, and it did not include the facilitation by administrators:

> I think just the way it was presented with the videos and then some discussion with the other teachers, and then actually doing the hands-on activities and the talking about what
did you, why did this happen and what did you see and what did you observe, and the whole speculating like what would happen if we did this other thing. (Alexis, Interview)

Only when asked during interviews who they felt had proven particularly helpful in supporting their learning of the NGSS, did two focus teachers acknowledge that the facilitators had played a role in enacting sessions with one of these teachers recognizing that the lead facilitator “did a great job leading the program.”

How one administrator, Janice, facilitated teachers’ first exposure to productive talk in a position driven discussion provides an example of how the facilitation of the NGSX exposed them to experiences congruent with the intent of NGSX. In Unit 4 of the NGSX pathway, teachers watched a video of a female teacher performing an experiment with two volleyballs. In the video, she weighs the two balls and students can see that the balls weigh the same. She then takes one of the balls and pumps more air into it and asks students to predict what will happen when she weighs the two balls again. The video ends and Janice has participants complete an online poll of what they think will happen. Janice then facilitates a position-driven discussion with participants in the PD, asking them to take on the role of the students in the video:

Janice: Would anyone like to share a position and give justification?

Person 1: I think the blue ball will get heavier as she added air, because air has mass and so more air, more mass it will be heavier.

Janice: Anyone like to agree or disagree?

Person 2: I disagree, because when you add air to something it’s like a balloon.

Janice: Would anyone like to agree or disagree?

Person 3: I’ll take the third point of view, unchanged, because air won’t weigh that much.
Janice: Is there anyone who would like to disprove any of these claims?

Person 4: Well, not all balloons go up.

Person 5: I said if I add if I add more air puppies, there has to be more of them, it can’t be lighter.

Janice: Would anyone else like to add? (Fieldnotes, Unit 4)

In the above episode, Janice attempts to model what a position-driven discussion may look like in a classroom. Although Janice missed some opportunities to press teacher/students for their reasoning (instead she moves to “Anyone like to agree or disagree?”) and for evidence to counter others’ claims (instead she asks for teacher/students to “disprove” others’ claims), overall, her modeling of a potential position-driven discussion proved adequate. Her attempt provided an object of discussion, and combined with the video of the teachers’ classroom, helped teachers to realize the importance of not “telegraphing” an answer to students. In small groups during this episode, Chrystal, a focus teacher, noted “The build up was good” and emphatically shares with astonishment, “All that time, she’s not put the ball on the scale.”

New adaptations created by facilitators created opportunities for teacher learning.

After working through some of Unit 5 of the NGSX pathway, facilitators realized that they would have to adjust their implementation of the upcoming sessions in order to meet required elements of the NGSX and best support teachers’ learning. As brought to the facilitators’ attention by the first author, the participants had not completed previously assigned “On Your Own” activities where teachers take ideas and tools from the NGSX into their classroom, or these activities had not yet been formally assigned to participants. Specifically, none of the remaining eight teachers that returned to the NGSX had completed an activity from Unit 4 that called for teachers to utilize the “Talk Moves” in their classroom and submit a media file of their
use. Nor did facilitators walk participants through the logistics of an activity from Unit 5 that called for teachers to utilize “Public Representations” in their classroom and document their use. Janice entered into a dialogue with the first author. Janice worried about “rushing just to complete all that we’ve missed and Unit 6,” which she had the task of implementing next. Together, Janice and the first author developed a new “Unit 5.5” where teachers would have the opportunity to plan their implementation of these two tools, something not explicitly designed for in the NGSX.

During the session for Unit 5.5, Janice facilitated planning time for the teachers for each of the tools which fostered productive discussions of how to actually achieve the implementation of these tools in the classroom. Teachers first discussed in pairs or small groups their potential approaches for each tool before sharing their plans with the whole group for more input. During small group work, Andrea and Chrystal worked together to identify a place for Chrystal to use the “Public Representations” with earth and space science materials. During this process, Chrystal shares with Andrea that she recognizes the inadequacy of her past approaches for having students develop a model explaining day and night and sees the summary table as a useful support:

I had them analyze a couple of models and then they picked one that was right and then one that didn’t make any sense. […] Then they jumped ship from a semi-accurate one to a ridiculous one. […] It was a good sheet but the weakness in this is me not providing the best opportunities for them to get info to fix their models. So this is where I think the summary table can help. (Chrystal, Fieldnotes, Unit 5.5)

Chrystal had found her previous approach of having students choose a model from a set of presented models for day and night as problematic, particularly in that it did not get at a key
characteristic of developing and using models where students iterate on their models based on analysis and feedback. In seeing the summary table as a potential remedy, Chrystal has used what she knows of the summary table to make sense of changes she could make in her own instructional practice.

Teachers also had productive discussions that led to new learning when planning for how to implement “Talk Moves” in their classrooms. Andrea and Chrystal discussed how Chrystal could integrate a discussion using Talk Moves into an upcoming lesson on layers in earth science. Through their planning together, Andrea has Chrystal consider new possibilities for the lesson in how the Talk Moves can support students in writing Claims-Evidence-Reasoning scientific explanations:

Andrea: What you were just talking about with the layers could work because of the explanations.

Chrystal: Its very me-guided with their models, hard for them to jump, today was “Here’s all the layers, you know the rules of layers, the fossils… and now what is first and what is second?” They needed me to talk through the first two. That needed a lot of me-guided and we are going to finish tomorrow.

Andrea: To start, you can record and see where it goes.

Chrystal: Yeah and at the end they are going to do CERs with a cartoon and dinosaurs – so they are doing some CERs like that.

Andrea: Do you have kids talk before CERs?

Chrystal: This I was planning on having them do it with partners because most of the group talk happened as a dialogue with me in them, I could…

Andrea: It could be rich.
Chrystal: Maybe we could talk about it, first time seeing it in the conversation and then they could go to write it.

Andrea: It could be a good conversation. (Fieldnotes, Unit 5.5)

Chrystal had not considered the possibility of using a discussion with Talk Moves to support students in writing more effective scientific explanations (in essence, supporting them in engaging in argument with evidence). With Andrea’s suggestions, made possible by the planning time provided by the facilitators, Chrystal saw new possibilities for how to structure her instruction using Talk Moves and support students in engaging in possibly a set of science and engineering practices from argumentation, to explanation, to developing and using models. In the episodes highlighted here, the facilitators’ decision to create a new Unit 5.5 focused on planning how to use NGSX tools resulted in productive learning opportunities for teachers around the NGSS and how to support students in engaging with science and engineering practices like modeling.

Claim 3: Mediation of Teacher Learning about the Practice of Developing and Using Models and NGSS

In addition to examining the influence of facilitation on supporting teacher learning of the NGSS, this study also explicitly focused on how the activities and tools embedded within the NGSX program mediated the development of teachers’ understanding of the practice of developing and using models. Patterns of co-occurrence between the NGSX activities and tools suggested participants often referenced or experienced these items in close proximity to one another within the NGSX PD activity setting (see Table 4). Particularly high co-occurrences between codes for videos played in the NGSX and discussions within the NGSX (50 co-occurrences), specific models introduced in the NGSX and videos played in the NGSX (28 co-
occurrences), and discussion and investigations (28 co-occurrences) indicate the high degree to which participants experienced or referenced these particular tools and activities in close proximity to one another.

Table 4

Co-occurrence of NGSX activities and tools with one another across all data sources

<table>
<thead>
<tr>
<th></th>
<th>Specific Model</th>
<th>Video</th>
<th>Investigations</th>
<th>Posters</th>
<th>NGSX Website</th>
<th>Discussions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discussions</td>
<td>14</td>
<td>50</td>
<td>28</td>
<td>6</td>
<td>24</td>
<td>-</td>
</tr>
<tr>
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<td>20</td>
<td>6</td>
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<td>-</td>
<td>24</td>
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<tr>
<td>Posters</td>
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<td>-</td>
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<td>-</td>
<td>17</td>
<td>7</td>
<td>20</td>
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<tr>
<td>Specific Model</td>
<td>-</td>
<td>28</td>
<td>19</td>
<td>4</td>
<td>7</td>
<td>14</td>
</tr>
</tbody>
</table>

Analysis of teachers’ reflections on their experiences in the NGSX suggests the NGSX’s sequence of investigations and building of specific models, interleaved with discussion activities and video presentations, helped build teachers’ understanding of the practice of developing and using models. In particular, analysis of excerpts from structured interviews, where focus participants responded to prompts that asked about what aspects of the the NGSX were most helpful in supporting their learning about the NGSS and the practice of developing and using models, supports claims of the effectiveness of having teachers experience an interleaved arrangement of NGSX tools and activities. In following response from Stephanie, she explains how tools and activities embedded within the NGSX supported her learning about the practice of developing and using models:

I think the opportunity to really talk with other teachers in the study groups, and to actually do a lot of the modeling and the activities that they do, you know, through the video. As they introduce an idea, then we would either do the actual investigation or we’d draw you know, our imaginings of what’s happening on a molecular level and kind of
explain it. As we talk through those explanations and made sense of our own understanding. And it was always such a rich dialogue along the way. (Stephanie, Interview)

In this excerpt, Stephanie describes various tools and activities in the NGSX, such as discussion, videos, modeling a specific “idea,” and investigations. She describes these activities not as occurring in isolation from one another but occurring in a sequence or arrangement that she saw as supportive of her learning. In particular, she notes the presence of “rich dialogue along the way,” indexing the interleaving of discussion among other NGSX tools and activities. Of the eight focus participants, six provided responses similar to Stephanie’s with references to multiple tools and activities in the NGSX sessions and how they supported their learning.

While some participants developed a deeper understanding of modeling, from a static representation to a representation that could explain a phenomenon and that could be revised over time, some teachers’ understanding of modeling did not change significantly. Through an examination of two case studies, we illustrate how teachers took up elements from the NGSX to support their understanding of the NGSS and modeling, chiefly (1) investigations, where teachers took on the role of students and engaged with phenomena through constructing and revising models and other science practices; (2) NGSX videos played during the PD sessions; and (3) structured discussions and reflections embedded within the design of the NGSX. We also examine how the sequencing of these tools’ use supported teachers’ learning and the development of their understanding of modeling.

**Case 1: How the NGSX tools and activities supported Jane’s understanding of developing and using models.** Prior to joining the NGSX program, Jane had very little exposure to the NGSS having only “found out about the NGSS standards pretty much right before” getting
an invitation to join the NGSX program by the district facilitators. Her initial examination of the NGSS led her to feel excited at the prospect of teaching science as the NGSS called for: “I felt like those standards were the standards that my students deserved to be learning and I wanted to learn more about how they worked and how to read them and how I could implement them.” In terms of modeling, prior to participating in the NGSX, Jane felt that she did have “some ideas on how to do these things” but that she had “not received enough formal training on how to do so to feel effective.” Moreover, Jane felt that in her years of teaching prior to her exposure to the NGSS and participation in the NGSX, she only had her students use models in a rudimentary manner: “Like I wasn’t having kids think of doing science as using a model and using models in their predictions. Probably my second year, the closest we go to models is like looking at some existing models that other scientists created but not even necessarily using them.”

Jane credits her experiences in the NGSX sessions with increasing her understanding of the NGSS and science and engineering practices, notably developing and using models. While Jane found individual elements of the NGSX as beneficial to her learning, such as the “awesome classroom videos” which she has shared with colleagues at her building, she found the way the NGSX organized experiences and how it positioned teachers as learners as the most effective elements supporting her learning of the NGSS:

So I really appreciate that, that you get to be a learner and that you have to do the same type of work that you would be asking students to do in this collaborative way […] I really appreciate that. And then I think, you know, the units are sequenced very appropriately and so once you get a taste of how it feels to be a learner and how it feels to develop a model and then use a model and refine and revise a model, that’s when you start thinking about you know, structures for discussion or sticky note revisions, you
know? So I really like the sequence and that opportunity to be a learner. (Jane, Interview)

Jane found elements within the NGSX as having great utility in supporting her learning, such as “collaborative” activity that leads to developing, using, and refining models which leads to discussions, but does so within the context of her getting “to be a learner.” This active learning approach that Jane found so appealing contrasts to previous PD experiences that Jane participated in, where she “just like sat in a meeting and [was] talked at.”

Jane actively embraced what the NGSX had to offer, including the collaborative lab activities within the NGSX sessions. She found the lab and modeling activities investigating air pressure particularly helpful in developing her understanding of how to structure sequences of activities to support students in engaging in modeling. When talking about what she learned about modeling from the NGSX activities, she offers:

So we didn’t do the plastic bottle in hot water experiment to prove that the air pressure on the outside is higher than the air pressure in the inside. We used that to uncover our existing knowledge and then we used following investigations to refine that knowledge and develop that model. (Jane, Interview)

In this excerpt, Jane shares her realization that the experiment within the NGSX supported her in further refining her model of air pressure. Jane found the instructional model she experienced as “a learner” within the NGSX so compelling, that she has since sought to bring similar experiences to her own classroom: “Well, I liked again, like the sequence of how we developed and used our models because they gave me like a template for how I could roll that out in my own class.”
In terms of in what ways Jane did or did not increase her understanding of the NGSS and modeling as a participant in the NGSX sessions, Jane developed an increased capacity to engage her students with instruction aligned to the NGSS. In a pre-post survey, Jane moved from feeling “somewhat confident” to teaching in ways called for in the NGSS to “very confident” at the conclusion of the NGSX. She admitted, however, to not having a working understanding of how to integrate the crosscutting concepts into her instruction, something she hopes the NGSX will address in the future. In terms of her confidence in engaging students in developing and using models, Jane reported a positive shift from “unfamiliar” to “confident”. Showing how her understanding of modeling has changed since her involvement in the NGSX, Jane reflects on her previous conceptions of modeling within the context of her chemistry classroom:

> When I was teaching at the beginning of the year about the atom, we talked about how the model of the atom changed, developed over time, and it just, the way, you know, it’s not the same topic and you don’t have the same tools, but you start with something and then you continually refine it, and it’s never exactly the same. That’s not the point, you know? It’s like you use it to predict things and explain things. (Jane, Interview)

Jane recognizes how her past instruction for the atom, while providing an account of how the model of the atom changed over time, missed “the point.” She critiques this past approach as not actually having students engage in a key aspect of the the practice of developing and using models, to “predict things and explain things.” This new understanding of the nuances of engaging in the practice—from having students learn about models of a phenomenon to having kids actively develop and use models of a phenomenon—demonstrates a working understanding of how the NGSS conceptualizes the practice.
Case 2: How the NGSX tools and activities supported James’s understanding of modeling. James, like Jane, had some prior knowledge of the NGSS prior to participating in the NGSX. James had heard about the NGSS through a colleague at his school and found the “structure” of the NGSS attractive, particularly the practices as he felt they “really brought things together.” Expanding on how he thought about the practices prior to the NGSX, James shared how he had placed argument at the center of the practices and how practices support one another: “I began to think about that with science, and I really believe that when you prepare them for that argument, when you prepare then to make a good claim and support it with evidence you know all the other scientific practices can be supported through that.” In terms of his initial conceptions of the practice of developing and using models, James provided in a survey an example of an ideal modeling activity for students prior to his participation in the NGSX. In this activity, students use tubes, valves, and other devices to build a working representation of how the heart functions. The purpose of this activity, according to James, is for “students to understand how the heart is constructed and how it is able to keep blood flowing on a daily basis.” This purpose emphasizes students’ understanding of the structure of the heart but does not reflect a “three-dimensional” conception of learning in which students apply their understandings of disciplinary core ideas and crosscutting concepts in the context of engaging in scientific practices to explain a phenomenon. Relatedly, this activity suggests only constructing a static representation of the heart and does not emphasize important elements of engaging students in the practice of developing and using models, such as model revision in light of new evidence about a phenomenon.

James feels his participation in the NGSX sessions supported his learning of the NGSS and how to engage students in science and engineering practices, like developing and using
Like Jane, James found the lab and modeling sequences as impactful. In particular, James said the modeling and lab activities around air pressure provided him with experiences that he could bring to his classroom: “particle modeling the air puppies model really helped me to understand that structure and especially how to teach that, um I think that's kind the big one for me.” Additionally, James, found the arrangement and organization of elements within the NGSX conducive to his learning:

I like the that changeup between the videos and the than being short and the teachers being able to discuss that particular those particular videos that discussion was very helpful all the time, I think the video piece and chunking that online commenting and posting I think that's valuable something I do sometimes in my classroom. (James, Interview)

Relatedly, James recognized the importance to his learning of having discussions interleaved with doing activities where teachers “let go of our teaching mode and get into a student mode,” stating that these experiences facilitated active examination of his understanding of the NGSS and modeling. The benefits of what James calls “student mode,” echoes sentiments from Jane around how the NGSX situated her to “be a learner.”

In examining in what ways James did or did not increase his understanding of the NGSS and modeling, James did develop some conceptions of developing and using models as called for in the NGSS. In reflecting on how he his approach to engaging students in the practice of developing and using models has changed since he began participating in the NGSX, James said that he recognizes now the need to provide students with adequate time to develop a model and purposefully revisit their model over time: “I think giving them more time to wrestle with the model, giving them time to go back to the model and not just oh here's the worksheet and go do
it and then I'll grade it and then you're done.” This commitment to having students “go back” to their model over time suggests an understanding of how models undergo revision over time. This notion is bolstered when looking at a post-survey response of James where he offers his idea of an ideal modeling activity: “The air pressure 2L bottle temperature change lab will provide the opportunity to build a model and continue to alter with new experiences.” The chance to “continue to alter” a model suggests some understanding of how models can change over time in light of new evidence.

While James showed an understanding of some aspects of the practice of modeling, in other ways his understanding of developing and using models and the NGSS seemed more limited. When talking about how he had his students engage in the practice, James emphasized the importance of developing a visual representation, such as in the purpose he gives for his ideal modeling activity on the post-survey: “Not only to understand air pressure and molecular movement, but also the skill of drawing a model to explain the unseen/abstract phenomena.”

Models can take numerous forms from not only the visual but also the mathematical and beyond (National Research Council, 2012). James’s emphasis on visual models may reflect an emphasis of visual modeling within the NGSX that he sought to emulate. In addition, James’s understanding at the conclusion of the NGSX on the role of science and engineering practices in instruction reveals a more traditional process orientation, indicating that he, in contrast to Jane, did not engage deeply with important aspects of the NGSX. James describes how students can engage in “discussions to get their ideas out so they can make those hypotheses so they can work through that whole argument even if they don't have evidence just the evidence of the thinking process.” This conception, where “if they don’t have evidence,” but can engage in argumentation runs counter to the notion of “three-dimensional” science learning.
Uptake of NGSX Tools by Teachers

The last focus of this study centered on how classroom adaptation and implementation of tools from the NGSX program mediated the development of various teachers’ understanding of the practice of constructing and using models. Overall, the largest uptake of NGSX tools by teachers for their classrooms occurred with talk moves, public representations, and specific models from the NGSX. As confirmed through classroom observations or reports from teachers during interviews and NGSX sessions, researchers determined that six of the eight focus participants employed talk moves in their classrooms, four of eight participants employed at least one type of public representation in their classroom, and four participants drew on specific models from the NGSX in their classroom, chiefly a model to explain air pressure phenomena called the “air puppies” model. Generally, we found that teachers used these tools largely “as is” to fit the content of their classroom. Additionally, some teachers used these tools to support their students in modeling activities and brought their experiences of using these tools in their classrooms back to subsequent NGSX sessions to provide further learning opportunities.

Below, we further explicate our findings by first providing patterns of evidence, primarily from the application of our coding scheme, which show the types and levels of uptake teachers demonstrated for each tool. We also present patterns of evidence for references and uses of NGSX tools across classroom activity settings and the NGSX PD activity setting. We then highlight through two case studies (1) the manner by which teachers took up tools from NGSX for use in their classrooms, (2) how teachers planned and implemented talk moves and public representations in their classrooms mainly as part of “On Your Own” assignments, and (3) how teachers, unprompted, took up specific models from the NGSX in their classrooms. In addition,
we highlight a short episode wherein teachers formally brought their experiences from implementing tools from the NGSX in their classroom back to an NGSX session.

**Types and levels of uptake of NGSX tools.** The application of the coding scheme provided patterns of evidence for how participants took up NGSX tools and which tools showed the most uptake (see Table 5). In terms of the level of uptake for tools, participants showed a positive affinity, as denoted through the code *subscribing to tool*, for a variety of tools from the NGSX, suggesting that some form of these tools had a higher likelihood of uptake for use in teachers’ classrooms. Some teachers at times, however, did not completely subscribe to all tools, as indicated by counts for *partial take-up*, which suggests teachers saw limitations or had reservations for certain tools. As for the rejection of a tool, coded as *failed take-up*, the one instance detected occurred during an interview with Alexis in regards to the talk moves, which she felt were “redundant” to her existing practice. Of note, Alexis ultimately did enact one short discussion using talk moves in her classroom as part of an “On Your Own” assignment.

In determining which NGSX tools focus participants actually used in their classrooms, we examined patterns in how participants took up tools, as captured by the codes *prompted take-up* and *unprompted take-up*. When researchers observed participants using or referencing NGSX tools to complete “On Your Own” assignments in the NGSX—tasks that called for participants to implement particular tools in their classroom—they coded these excerpts as *prompted take-up*. Talk moves and public representations, the focus of “On Your Own” assignments, showed high co-occurrence counts for *prompted take-up* which suggests these tools experienced high uptake and use in classrooms. Indeed, inspection of excerpts for the eight focus participants confirmed that six teachers (Chrystal, Stephanie, Elizabeth, James, Jane, and Michael) completed the “On Your Own” assignment for using talk moves in their classrooms and four teachers (Elizabeth,
James, Jane, and Michael) completed the assignment to use public representations. Also, three focus participants (Crystal, Elizabeth, and Jane) reported during interviews that they planned to continue to use talk moves in their classrooms whereas two focus participants (Jane and James) reported that they would continue to use public representations in their classrooms. These expressions of continued use suggest strong uptake for these NGSX tools. In terms of limitations in our analysis, although the application of codes for specific models, investigations, and videos occurred within the parameters set forth in our coding scheme, checking of excerpts revealed counts of prompted take-up for these tools were mainly the result of their co-occurrence in excerpts with other elements, such as talk moves and public representations.

Table 5

<table>
<thead>
<tr>
<th>NGSX Tools</th>
<th>Types and Levels of Uptake</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Subscribing to Tool</td>
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<td>Talk Moves</td>
<td>16</td>
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<tr>
<td>Public Represent.</td>
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<td>Investigations</td>
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</tr>
<tr>
<td>Videos</td>
<td>19</td>
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</tbody>
</table>

*All or high proportion of counts attributed to inadvertent co-occurrences in excerpts

The code unprompted take-up, where participants used tools from the NGSX in their classrooms without any formal prompting by the NGSX design, provided another indicator of which tools teachers actually used in their classrooms. Instances of unprompted uptake, being not specifically planned for in the design of the NGSX, also indicate a high level of teacher commitment to a tool. Talk moves and public representations showed higher counts for unprompted take-up, indicating higher uptake. Three focus participants (Jane, Elizabeth, and
Crystal) spontaneously employed talk moves in their classrooms, supporting previous patterns of strong uptake for talk moves by these participants. Public representations had lower counts indicating lower uptake. Examination of relevant excerpts showed they related to Andrea reporting on how she introduced public representations to classroom teachers outside the NGSX. Since the introduction of public representations did not occur until late in the NGSX sequence and was accompanied by an “On Your Own” assignment prompting their implementation, the lack of other instances of unprompted take-up for this tool does not prove surprising. Regarding specific models from the NGSX, the higher counts observed indicate higher uptake. Excerpts for this pattern pertained to four teachers (Jane, James, Stephanie, and Elizabeth) who each invoked the “air puppies” model from the NGSX within their classrooms. Lower code counts observed for unprompted take-up with investigations reflects the activity of one teacher (James) who used specific investigations from the NGSX in his classroom. Examination of excerpts revealed that the higher counts seen for videos stemmed almost entirely from inadvertent co-occurrences, save for two instances. In each instance, teachers did not play NGSX videos in their classrooms; rather these two teachers (Jane and Elizabeth) reported pulling out information or principles from the videos for use in their classroom instruction.

**NGSX tools across activity settings.** Examination of the degree to which participants used or referenced the NGSX tools within classroom activity settings and the NGSX PD activity setting, or made reference to such settings, also provided patterns of evidence that support the claim that participants took up certain tools for use in their classrooms (see Table 6). The presence of tools occurring in both classroom activity settings and the NGSX PD activity setting suggests that some movement of tools between settings did occur. As such, with data showing talk moves, public representations, and specific models occurring across both settings supports
earlier assertions that these tools saw uptake by teachers for use in their classrooms. While some participants (e.g. James) did intentionally bring investigations from the NGSX into the classroom, a limitation of this data as presented rests with the fact that the vast majority of occurrences observed for investigations in classroom activity settings related to investigations developed by teachers. As such, we cannot claim high movement of NGSX-specific investigations into classrooms.

Table 6

Occurrence of NGSX tools across classroom and NGSX PD activity settings

<table>
<thead>
<tr>
<th></th>
<th>Talk Moves</th>
<th>Public Represent.</th>
<th>Specific Models</th>
<th>Investigations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classroom Activity Setting</td>
<td>60</td>
<td>36</td>
<td>27</td>
<td>78*</td>
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<td>NGSX PD Activity Setting</td>
<td>34</td>
<td>26</td>
<td>55</td>
<td>50</td>
</tr>
</tbody>
</table>

*High proportion of occurrences reference non-NGSX investigations

Notably, further examination of excerpts found that while the vast majority of tools moved from the NGSX PD activity setting into classroom activity settings, some movement of tools back into the NGSX PD activity setting from classroom activity settings did occur. In addition to the formalized attempts occurring late in the implementation of the NGSX to have teachers bring their classroom experiences of using NGSX tools back into the NGSX PD activity setting, some teachers would also spontaneously recount their classroom implementation of tools from the NGSX during NGSX sessions. Crystal, for example, had tried using the talk moves in her classroom prior to the formal “On Your Own” assignment calling for their implementation. Here she recounts her experience and assessment of the talk moves during an NGSX session:

Out of anything we did last semester these talk moves were something I could do right
now and we’ve done two academic circles where I used them more, but I realize I have
that problem of getting too excited, so I really like the talk moves, I am suggesting to
look at them and maybe try them if it’s not something you naturally do. (Crystal,
Fieldnotes, Unit 5.5)

In this excerpt, Crystal testifies to the utility of the talk moves, even going so far as
recommending that others use them in their classrooms. She cites her personal experiences of
using the talk moves in her own classroom and how they have helped to address a self-perceived
shortcoming in her instruction (“that problem”). This unprompted endorsement extolling the
usability of the talk moves occurred just prior to participants being assigned the “On Your Own”
assignment to use the talk moves in their classrooms, which obfuscated the influence Chrystal’s
comment may have had on other teachers’ uptake of this tool. This instance, however, still
highlights how the inclusion of classroom experiences in professional development settings can
serve to potentially influence teachers’ uptake of desired tools and teacher learning.

**Case 1: How Jane took up NGSX tools in her classroom.** In transitioning to a closer
examination of individual teachers’ experiences with tool uptake, we begin with the case of Jane.
Throughout the implementation of the NGSX, Jane consistently subscribed to the utility of the
tools presented. The purpose of the NGSX as Jane framed it was to “figure out how you can
implement the NGSS in your classroom, and particularly focuses on tools for developing public
reasoning and developing and using models.” Tools in Jane’s view can support the sort of shifts
called for in the NGSS, shifts Jane sought to implement in her own classroom. This desire comes
across when Jane talked about using the talk moves:

Yeah. It’s [Talk Moves] so user-friendly, and then it’s just like “Oh. That’s how I do
that.” Cause everybody kind of has those goals in mind whether they are so clearly
articulated or not, but then it’s like “Oh. If I want them to do that, this is what I can say.”

(Jane, Interview)

Jane subscribed to the utility of the talk moves because they supported her instructional goals. Although Jane did not attend Unit 5 where facilitators introduced public representations—such as the summary table, explanation checklist, and sticky notes and language stems—Jane accessed the materials on her own through the website and subscribed to the utility of these tools:

I really like especially NGSX, some of the later units. Like the one where we learned about the sticky note model revisions and those tools, the summary chart and those things, I think are helpful for all students. And the stems for the stick revisions are really helpful for lower students. I want even more of those. I think they are really effective, you know? (Jane, Interview)

Jane goes beyond simply extolling the tools introduced by the NGSX but notes how the tools support “all students” including “lower students.” This demonstrates how her uptake of the tools occurs according to their capacity to support her instructional goals.

In terms of implementing the tools in her classroom, Jane used tools from the NGSX in her classroom to various degrees during her participation in the NGSX. When reflecting on her use of the talk moves in her classroom, Jane describes how practice around discussions productively shifted:

One of the teachers was talking about how there’s like that kind of common response where the teacher is like asking a question and looking for a particular answer. I used to do a lot more of that than I do now. Now I don’t really do that, really. Every once in a while I do that if there’s a particular thing we need to make sure we’ve gotten, but I am really trying to do more of the like the Talk Moves so that kids are forced to engage in
each other’s thinking. And I think that kids are starting to notice that because they’ll like
make fun of me sort of. (Jane, Interview)

Jane recognizes how she has shifted from a more traditional mode of engaging in discussion to
discussions where students construct their knowledge through discourse. Jane feels the talk
moves have helped students “to engage in each other’s thinking,” so much so that have an
awareness of her moves in the classroom.

After completing an “On Your Own” assignment where she implemented public
representations and engaged her class in discussion, Jane laments that the discussion did not
meet her expectations: “I wasn’t happy with the discussion. I have had some really successful
discussions in the past where everyone participated but this was not one. I just need to use the
talk moves all the time.” Notably, Jane sees consistent use of the talk moves as a potential
solution to what she interpreted as an unsuccessful class discussion. Even though Jane had
already brought other tools, the public representations, into the lesson, she realizes that the use of
the tools from the NGSX can and should overlap in her classroom in order to support students in
achieving her instructional goals and the shifts called for in the NGSS.

Beyond the use of talk moves, Jane also made efforts to integrate public representations,
specifically the summary table and sticky note and language scaffolds. Jane felt that her use of
the public representations in her classroom led to more desirable outcomes than other traditional
approaches she has used:

[W]hen I’ve used them [public representations], I’ve seen students like all students
thinking really rigorously.[…]They were thinking really, really hard, and engaging in
each other’s reasoning, and when I teach in a way that’s like that the more traditional way
of teaching, I think I lose some of those kids a lot faster, when I'm, you know, doing something on the board and expecting them to copy it. (Jane, Interview)

Jane felt her use of the summary table and sticky note and language scaffolds supported her in making an important shift in her instruction where students engaged in more active, rigorous thinking as opposed to simply copying information. In implementing the public representations in her classroom, Jane used the tools essentially “as-is.” For example, she utilized the same headings and format shown for exemplar summary tables from the NGSX sessions and she used the same language for the language scaffolds that accompany the sticky-note tool. Jane used her own judgment and expertise, however, in enacting these tools. After using the summary table a few times, Jane recognized that not all students contributed to the construction of models. In response, Jane gave each student their own copy of the summary table template that they could fill in before going to the class summary table. She also fostered an expectation that everyone participates and contributes to the model by requiring “that every student’s handwriting should be visible on the models.” These instructional moves, Jane felt, led to a “big improvement.”

**Case 2: How James took up NGSX tools in his classroom.** While James reported finding some of the tools presented within the NGSX as useful, he also demonstrated some skepticism at the ease of applicability of some tools. James did not explicitly report using formal tools introduced within the NGSX within his classroom, such as talk moves and public representations. Instead, James took up complete investigations and specific models he experienced in the NGSX sessions and brought them to his classroom. Specifically, James brought experiments and modeling activities around air pressure from the NGSX sessions into his classroom. Here, James subscribes to the utility of these lab and modeling activities:
I did with the air puppies in the model putting uh the 2 L bottle into the water and changing the temperature walking them through the process that was really engaging for them and I think they appreciated that time to really struggle I had one student his answer was just as though I was talking I really did not give them any prep time or rather any connectedness to or instruction content wise for him to be able to speak as he did. (James, Interview)

James, on his own without any prompting by the NGSX design or facilitators, took this lab sequence from the NGSX sessions and implemented it within his classroom. For this activity, James had his students create representational models of the phenomenon in the lab, using a format similar that used by teachers in the NGSX. For some formal tools introduced, specifically the explanation checklist, James only partly took up the tool, wanting more information on how to enact the tool after seeing its use in a video: “I would like to see a bunch of them a bunch of [explanation] checklists instead of hers, this picture is about speciation, that’s great – but what activity did you do?”

James showed more take up of specific tools put forth in the NGSX sessions after receiving the “On Your Own” assignments that called for teachers to try out the talk moves and public representations in their classrooms. During an observation of James’ classroom to see the implementation of NGSX tools, James utilized talk moves, elements from the sticky notes tool, as well as having students engage in visually drawing models of a phenomenon, echoing his previous modeling instruction. James explained to the students how he wanted to “push their thinking” through talk using the tools provided. These tools included cards that had “Pose a question” and “Build on an idea” written on them, language that mirrored categories students would assign to comments used for the sticky-note tool. James has the students take up this
language for a different purpose: as prompts in small group discussions geared at explaining why water entered or left a celery stick. During discussion, James employed recognizable talk moves, such as asking for someone to summarize what someone else said (i.e. rephrase) and whether students agree or disagree with another student’s idea. James employs these techniques to aid students developing a visual model that can “explain the direction of the water.” James mix of techniques suggests an understanding of how tools and techniques introduced within the NGSX can work together to support students in engaging in modeling.

While James did have students engage with the categories from the sticky note tool, this implementation departed from the intended design of the tool. In this series of lessons, however, James did provide his students with the opportunity to engage with the summary table in a more straightforward fashion. James shared that he had students engage with the summary table at the conclusion of each lesson over the course of several lessons as intended for the use of the summary table. Additionally, James used a similar language and organization depicted in the exemplar summary table introduced during the NGSX sessions, adopting the tool almost “as-is.” James use of the summary table, however, did not have students build and revise their understanding of an anchoring phenomenon as demonstrated within the NGSX sessions. Instead, James used the summary table in a more traditional fashion to hold information students learned about a cell more generally (e.g. “Cells make up living things,” “cells are microscopic”). Regardless, James felt that his use of the summary table coheres with the intentions put forth in the NGSX: “[The NGSX] helped me see how to keep the content relevant and the content connected throughout the unit, summary tables are an example in developing that.” James understanding of the intentions of the summary table, of keeping the “content” relevant, possibly reflects an orientation that does not reflect “three-dimensional” science learning.
Teachers’ bringing classroom experiences of using tools back to the NGSX.

Throughout the implementation of the NGSX, teachers like James and Jane would occasionally bring tools and ideas from the NGSX to their classrooms. Subsequent to these implementations, these teachers, usually unprompted, shared their experiences with their fellow teachers and other practitioners within the NGSX sessions. For example, Chrystal, after using talk moves in her classroom, reported back to the rest of the group—on more than one occasion—of her experiences with using them in her classroom to support productive discussions. The movement of these tools into the classroom, how teachers make sense of their use with colleagues could provide a rich professional development learning opportunity. District facilitators recognized as much. Although not called for in the original design of the NGSX, the district facilitators inserted time at the front of Unit 6 for teachers to share their experiences of using tools as called for in “On Your Own” activities. At the close of Unit 5.5, Janice told teachers that they wanted to ensure teachers had a chance to share their experiences: “[W]e can build in discussion time, we don’t want just Sam [first author] and the research team to benefit.”

Despite the potential for rich learning to occur during Unit 6 when teachers had the opportunity to share their experiences, this potential was not fulfilled. In large part, this seems due to the logistics of tweaking an existing unit and attempting to simply “tack on” another element. Looking at the agenda shared by Janice for the session, only 20 minutes were allotted for teachers to share their experiences. Tellingly, after teachers began to share their experiences, facilitators allowed for their conversations to run over the allotted time to approximately 35 minutes before facilitators felt compelled to move on to the dismay of some teachers. During this 35 minutes, Janice had the teachers “turn and talk” with the participant next to them and discuss
their experiences implementing the tools. She provided a series of guiding questions for their discussions:

1. Which of the talk moves did you use?
2. What happened after a talk move was used?
3. Which goals are well in place, and which do you want to work on?
4. Which tools did you use from Unit 5?
5. Why did you choose that tool?
6. How did that tool support student learning?

Perhaps due to the nature of these questions, teachers did not engage in deep back-and-forth discussions focused on imparting experiences with the intention of furthering teachers’ learning. Rather, teachers, more or less, simply “reported” their experiences. For example, one teacher noted that having students engage with an observable phenomenon through a lab investigation created student investment and ownership of the process of developing a model. Although an important idea worthy of further discussion, this comment did not get taken up.

A few exchanges between teachers did offer a glimpse into the potential for deeper learning opportunities afforded by having teachers share their classroom experiences in the professional development. For example, one teacher discussed how her students while using the summary table did well with drawing on evidence from the lab in constructing their models but did not do well in challenging and critiquing each other’s models. Another teacher suggested using another tool, the explanation checklist, in tandem with the summary table to improve this. This exchange indexes an important instructional approach realized to some degree in the practices of Jane and James, that using the NGSX tools in a sequential or overlapping manner can better support students in engaging with the practice of developing and using models.
Although the suggestion of bringing additional tools into the lesson was made and perhaps taken up by the teacher at whom the comment was directed, the opportunity to more deeply examine the very idea of using tools in combination passed by and others, notably facilitators, did not explore this idea further.

Having a more systematic approach to capturing and leveraging teachers’ classroom experiences seems a desirable direction. The potential in pursuing this direction for the design of the NGSX appealed to teachers as well. In talking about what was least helpful about the NGSX in terms of supporting his learning of the NGSS, James offered the following:

I think the challenge of spending some time in the class talking about our experiences talking about hey what happened when you implemented this summary table or what happened when you implemented a poster concept or a class discussion […] I think the units were helpful but they were focused on moving on, but not necessarily addressing what we had been learning on our own in class as we were teaching and listening to kids.

I think that's a real value to tweak some of those strategies. (James, Interview)

James feels that the NGSX could be improved if more opportunities existed for teachers to bring back and share their experiences. Rather than “moving on,” James wanted to have more opportunities to share and hear about what teachers had learned “on our own.”

**DISCUSSION**

This study examined the implementation of the Next Generation Science Exemplar (NGSX) professional development program in a large urban school district. This study provides evidence that selected tools and activities embedded within the NGSX supported the development of teachers’ understanding of the NGSS with a particular emphasis on the science and engineering practice of modeling. In terms of how the NGSX served to mediate teachers’
understanding, the array of online and in-person activities within the NGSX provided teachers with an innovative mix of mediational means that index recognized principles for supporting teacher learning within professional development (Moon et al, 2013). The degree to which the NGSX embedded the expertise of its designers within designed elements (e.g. videos, structured discussions) provides a compelling design direction for future science PD. In addition, the interleaving of activities—such as videos, lab activities, modeling activities, structured discussions and reflections—into productive sequences observed within the NGSX sessions may provide a possible design pattern for future PD.

Evidence also indicates the potential utility in designing for ideas and tools from a PD to cross settings from the PD setting to the classroom but also reveals potential challenges. Teachers implemented many of these tools and activities within their classrooms, with talk moves and public representations, specifically, the summary table, getting the most uptake. This result likely occurred because the NGSX required completing “On Your Own” assignments involving these tools. In addition, teachers found these same tools useful in supporting their instructional goals, which supports previous research suggesting that attending to teachers’ perceptions of the utility of elements introduced within a PD may predict take-up (Fishman, Penuel, Hegedus, and Roschelle, 2011). For some teachers, their implementation of some tools in their classrooms (e.g. talk moves), revealed an understanding of how to organize their instruction to support students in modeling as envisioned by the Framework and NGSS. However, some implementations by teachers may have reproduced aspects of traditional science teaching (e.g. teaching practices or core ideas in isolation). How to address these “lethal mutations” will likely prove challenging to PD designers.
Examination of teachers’ uptake and use of tools in their classrooms also revealed other insights. Notably, some teachers’ used multiple NGSX tools in a sequential or overlapping manner in their classrooms, demonstrating an intuition of the need to not have students engage in practices in isolation from one another (Bell & Van Horne, 2014). As the NGSX did not explicitly address this concept, this may provide a potential area for emphasis in future PD. In addition, efforts to further teachers’ learning, through having them bring their experiences from implementing tools and ideas in their classroom back to the PD setting, largely proved ineffective mostly due to logistical timing constraints and a format that promoted “reporting” rather than productive dialogue. Given facilitators’ and teachers’ belief in the value of such an activity and the potential upside for teacher learning if achieved more effectively, efforts to support bringing teachers’ classroom experiences of implementing tools back to PD settings merits further attention.

Lastly, this study showed how local implementation may influence the success of a designed PD. The district administrators who facilitated the implementation of the NGSX engaged in adapting the NGSX to address perceived needs. While some adaptations proved beneficial, other adaptations proved detrimental to teachers’ learning. Specifically, the logistical organization of the NGSX PD by local facilitators proved detrimental. These findings demonstrate the challenges for designers of PD who desire widespread implementation for their interventions. While the NGSX has a decidedly well-developed format with expertise embedded into many elements of its design, implementation across different sites introduces new variables that designers often cannot completely attend to. While the local facilitators shared the desire of the NGSX designers to support teachers in developing a deeper understanding of the NGSS and the practice of developing and using models, the approach as envisioned and the approach as
enacted ultimately differed. These differences occurred as a result of local facilitators’ judgments but also as a result of the NGSX surfacing pre-existing constraints in the district, such as no funds to pay teachers, and tensions, such as a lack of respect for science at the elementary level. The broken trust between administrators and elementary school teachers, in particular, echoes previous research of the importance of establishing trusting relationships between teachers and administrators in order to support initiatives (Lee, Leary, Sellers, & Recker, 2014).

An important limitation of this study centers on the sample of teachers who participated in the NGSX. As noted previously, the number of teachers participating in the NGSX dropped from twenty-one initial participants to eight consistent participants who became the focus participants in this study. These eight final participants, compared to their peers who left the NGSX, demonstrated high levels of motivation for learning about the NGSS and the practice as modeling. As such, while this study has shown evidence for the efficacy of the NGSX and its design in terms of supporting teacher learning of the NGSS and the practice of developing and using models, generalizing these results beyond the focus participants would be ill advised.

CONCLUSION

With states and districts seeking to adopt the NGSS and achieve the ambitious vision for science education within the Framework, supporting teachers in meeting the significant shifts called for in instruction will require teacher development in the form of professional development within educational systems like school districts (National Research Council, 2012, 2015b). This study examined the NGSX, a professional development program aimed at supporting teachers’ understanding of the NGSS with a particular emphasis on modeling. The NGSX has demonstrated promising design elements for organizing teachers’ learning of the NGSS and modeling. The hybrid online/in-person format provided valuable tools that proved
most effective when used in sequences and in combinations as the NGSX designers intended. This arrangement of elements in the PD (e.g. labs, videos, structured discussions, reflections) could provide a useful design pattern for other researchers developing science professional development programs, particularly those seeking to support teachers’ understanding of how to engage their students in other science and engineering practices beyond modeling.

In addition, this study has shown the clear importance of studying the implementation context of PD. Local facilitators will inevitably adapt or modify some aspect of an already designed PD. In this study, local facilitators erred in scheduling an extended break between the enactment of NGSX units. This logistical miscalculation impacted teachers’ participation with ripple effects for the richness of the PD experience and for building the capacity of the district to adopt the NGSS. In addition, facilitators made adjustments intended to support teachers in bringing NGSX tools to their classrooms and in productively bringing their classroom experiences of implementation back into the PD setting, all with the intention of furthering teachers’ learning. Although the latter effort of bringing teachers’ experiences back into the PD ultimately failed to provide meaningful learning, facilitators revealed they have expertise that can still productively influence future iterations of PD. The facilitators’ modifications raise issues of what approach designers of PD could adopt to support effective implementation. While facilitators may not have demonstrated absolute fidelity to the design of the NGSX as envisioned by its designers, they did seem to demonstrate integrity to the aims of the NGSX in that they sought to support teachers’ understanding of the NGSS and modeling. However, the effects of the modifications they made on the whole proved decidedly mixed.

The influence of the implementation context brings into relief the need for designers to consider the situated context of PD. From this study, this manifested most prominently around
the relationships between teachers, administrators, and researchers. Such relationships matter for implementing the NGSS at scale, specifically, across grades over an entire district. Building capacity for NGSS implementation will require considering how to design PD across grades to foster coherent experiences for students throughout their schooling. When the elementary school teachers felt slighted by the actions of local facilitators, surfacing a previously existing tension, it damaged opportunities to build coherence across grades. Navigating these tensions can make or break a district’s efforts to bring about science education reform in their schools. Efforts should be made to develop new design strategies that better attend to the situated context of professional development in order to support educational systems in achieving science education reform.
CONCLUSION

by

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CONCLUSION

This dissertation examined supports for the implementation of the Next Generation Science Standards (NGSS; NGSS Lead States, 2013) through three articles. Each article focused on how supports helped to address challenges facing a large urban district seeking to adopt the NGSS. Article 1, *Organizing for Teacher Agency in Curricular Co-design*, examined how supporting teachers’ agency in curriculum development through the use of a co-design approach and specific tools and routines can contribute to addressing the need for curriculum aligned to the NGSS. Article 2, *Relevant Learning and Student Agency within a Citizen Science Design Challenge*, examined how formal curricular materials that integrate a community-based citizen science design challenge can both expand student agency and promote learning that students see as relevant. Article 3, *Implementation of a Novel Professional Development Program to Support*
Teachers’ Understanding of Modeling, examined how a novel professional development program, the Next Generation Science Exemplar (NGSX), can support teachers’ capacity to engage their students in the practice of *developing and using models* by providing tools for modeling and supporting learning across classroom and professional development settings.

Common to all three of the implementation supports studied in this dissertation, and central to achieving the ambitious vision for science education put forth in *A Framework for K-12 Science Education* (*Framework*; National Research Council, 2012) and carried forward in the NGSS, is the notion of “three dimensional science learning.” Three-dimensional science learning calls for students to engage in science and engineering practices (dimension 1) in building their understanding of disciplinary core ideas (dimension 2) and cross-cutting concepts (dimension 3). Given that gaining entry into three-dimensional science learning occurs through students taking up science and engineering practices and applying them towards investigating phenomena (Reiser, 2013, 2014), this conclusion will provide high-level insights derived from the dissertation articles for supporting students in engaging in science and engineering practices.

Moreover, this conclusion will do so by addressing issues of organizational coherence around the issue of engaging students in science and engineering practices. The *Framework* posits that achieving its vision for science education will require a coherence of effort and activity between major elements of an education system (National Research Council, 2012). Accordingly, this conclusion examines three key areas of overlapping activity within a district where efforts to support students’ engagement in science and engineering practices should occur: curriculum development, professional development, and classroom instruction.

**Three-Dimensional Science Learning through Science and Engineering Practices**
Achieving three-dimensional science learning requires engagement with science and engineering practices. The Framework describes science practices as those scientists employ as they investigate and build models and theories about the world, and engineering practices as those engineers use as they design and build systems (National Research Council, 2012). The use of science and engineering practices allows for the realization of three-dimensional science learning as all science learning should involve engaging in practices to build and use knowledge (Reiser, 2013). Students engage in science and engineering practices to build pieces of disciplinary core ideas and connections to crosscutting concepts (Reiser, 2014). Demanding that students engage in science and engineering practices as part of three-dimensional science learning prevents teaching the practices as isolated skills apart from content and allows students the needed opportunity to actually experience the practices themselves in order to comprehend them (National Research Council, 2012). In this manner, students can appropriate science and engineering practices and develop agency around when and how to employ them, either individually or in an overlapping sequence (Bell et al., 2012), when exploring phenomena or addressing problems.

Organizing Curriculum Development Towards Engaging Students in the Practices

In order for students to engage in science and engineering practices in a meaningful and coherent manner, they need phenomena towards which they can focus their activity including the taking up of science and engineering practices (Reiser, 2013). Curricular materials have the capacity to help organize students’ experiences around investigating a phenomenon, leading to more coherent and meaningful science learning (Fortus et al., 2015). Ensuring that students have ample and meaningful opportunities with curricula to use science and engineering practices to investigate phenomena requires setting such experiences as a guiding design principle during the
development of science curriculum materials. Article 1 showed how the use of specific design tools and structures can help to continually foreground the need to develop instruction centered around phenomena that students explore through science and engineering practices. Specifically, Article 1 showed how the use of “skeletal” (Engeström, 2011, p.621) tools such as the Storyline tool from Reiser (2013) can effectively mediate productive design activity by requiring design participants to exercise their agency and leverage their expertise in taking up and completing such tools. Mediating with purposefully incomplete tools like the Storyline tool allows curriculum designers a means to effectively build on expertise already embedded within the tool, all towards ensuring that curriculum materials provide meaningful opportunities for students to engage with science and engineering practices as part of three-dimensional science learning.

Organizing Professional Development Towards Engaging Students in the Practices

To support students’ engagement in science and engineering practices, their teachers must have an appropriate level of understanding of science and engineering practices themselves. Supporting teachers in understanding the shifts called for in the Framework, including how to engage students in science and engineering practices, will require professional development and teacher training (National Research Council, 2012). Article 3 showed how designed features of a professional development program, the NGSX, can prove effective in supporting teachers’ understanding of science and engineering practices, notably the practice of developing and using models. Article 3 suggests that effective professional development around science and engineering practices requires having teachers engage in intentional sequences of complementary activities. These activities could include hands-on investigations of phenomena and developing models of these phenomena, interleaved with group discussions and supplementary support material, such as exemplar videos of classroom implementation or expert commentary. Article 3
also showed that developing a professional development program around a select few overlapping practices, notably in the context of investigating phenomena, can prove effective for teacher learning. Additionally, Article 3 suggests that while teachers will implement tools from professional development settings designed to engage students in science and engineering practices in their classrooms, teachers require and desire more support in how to implement such tools effectively in ways that embody the notion of three-dimensional science learning called for in the NGSS and the Framework. Professional development designers should seek to better capitalize on teachers’ inclination to take tools into their classrooms and their willingness to share their experiences of doing so back in professional development settings.

**Organizing Classroom Instruction Towards Three-Dimensional Science Learning**

The depth to which students engage in science and engineering practices depends on how much agency students experience in the classroom. The Framework calls for students to take up the practices in order for them to achieve activity resembling that of practicing scientists (National Research Council, 2012). Achieving this aim requires that students have the agency to “figure out” phenomena using science and engineering practices more on their own rather than “learn about” phenomena from their teacher (Reiser, 2014). Article 2 showed that modifications made to curricular materials by teachers can support or hinder students’ sense of agency and the degree of autonomy they have to engage in science and engineering practices. Teachers who adjust their instruction to let students’ “figure out” more aspects of their learning can experience a greater sense of agency and will engage with science and engineering practices in ways more similar to practicing scientists. On the other hand, teachers who engage in “hyper-mediation” (Gutierrez & Stone, 2002), or overly scaffold instruction, may take away opportunities for students to “figure out” more aspects of their learning and to more deeply engage in science and
engineering practices. This is not to say that scaffolds and instructional supports have no place in the classroom, rather that their use should be judicious so as to preserve opportunities for students to deeply engage in science and engineering practices. More research needs to occur on how teachers can achieve an optimal balance between providing guidance to support students while still maintaining students’ agency and maintaining opportunities to deeply engage with science and engineering practices in ways similar to practicing scientists.
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SUPPORTS FOR IMPLEMENTATION OF NGSS

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Education.


Appendix A

Article 1: Teacher Online Survey 1 (Freewrite)

This is a “six-minute freewrite” -- try and write continuously, giving two minutes to each question.

1) Imagine you could give a 30-minute presentation to the other teachers in your school about what you’ve learned the last five days.
   ● What would be the major topics of your presentation?
   ● What would you say about these topics?

2) If you were leading this process again with a new group, what would you change? What would you keep the same?

3) What concerns of yours have not yet been addressed?

Article 1: Teacher Online Survey 2 (Midpoint)

1) What is your name?

2) How would you describe your role in the project?

3) What aspects of the unit so far do you think work well and why?

4) What aspects of the unit do you have concerns about? How could these concerns be addressed?

5) What have you found to be helpful in facilitating your work during this project?

6) What do you need to further support your work during this project?

7) Do you feel your participation in the project is valued by others? If so, by whom and in what ways?

8) What other questions, concerns, or comments do you have that you would like to share?

9) How long did it take you to complete this survey?

Article 1: Critique/Feedback Survey

1) Your name
2) For which section are you providing feedback?

3) Rate the coherence of this section of the unit as high, medium, or low based on your review, using the storylines and individual lessons as a basis for judgment.
   a. High: Each activity builds a “piece” of the performance expectation, and helps add to our evolving answer to the driving question. It would be easy for students to articulate the purpose for the activity and its contribution to help answer the driving question. Activities related to Denver trees develop students’ agency both as knowers (of ecology) and doers (who can contribute to sustainable cities by their actions).
   b. Medium: Each activity builds a “piece” of the performance expectation, but it doesn’t add to our evolving answer to the driving question. If asked, students could articulate the purpose of the activity, but not its contribution to answering the driving question. Activities related to Denver trees develop students’ agency either as knowers (of ecology) or as doers (who can contribute to sustainable cities by their actions).
   c. Low: Practices are engaged in, but in isolation, without a purpose that moves toward mastery of the performance expectation and addressing the driving question. Students, if asked, cannot describe the purpose of the activity. Activities related to Denver trees do not develop students’ agency either as knowers (of ecology) or as doers (who can contribute to sustainable cities by their actions).

4) Justify your rating with evidence, and make concrete suggestions for how to improve the rating so it would earn a “high” rating.

5) What other feedback do you have for this group?
Appendix B

Article 2: Student Online Survey (Practical Measures)

1) Today in science class I felt… [Check all that apply]
   - Excited
   - Confident
   - Like a scientist
   - Confused
   - Bored
   - None of the above

2) Today I… [Check all that apply]
   - Asked a scientific question
   - Planned or did an investigation
   - Created or used a model
   - Used math to figure something out
   - Analyzed data
   - Wrote a scientific explanation
   - Designed a solution to a problem
   - Made an argument using evidence
   - Communicated scientific information
   - None of the above

3) What we did or learned about in class today is useful.
   - Yes
   - No
   - Unsure

5) What we did or learned about in class today… [Check all that apply]
   - Matters to me
   - Matters to the class
   - Matters to the community
   - None of the above

6) We learned about something today that connects to the challenge.
   - Yes
   - No
   - Unsure

5) Talking about our ideas today helped me improve my thinking.
   - Yes
   - No
   - Unsure
6) On the scale of 1 to 5 below, what best describes how you learned today?

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The teacher told us everything we needed to learn</td>
<td>We figured out some things on our own but the teacher told us the other things</td>
<td>We figured most things out on our own that we needed to learn</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7) OPTIONAL: What other thoughts do you have about today?

**Article 2: Student Interview Protocol**

Interview protocol to be administered at beginning and end of unit

What do you think the unit is about?

What have you done in the unit so far?
  - What have you done recently?
  - Why did you do that?
  - What is left to do?

What have you learned so far?

How useful is what you have learned so far?
  - How is it useful?

How much does what you’ve learned so far matter to you?
  - Why does it matter/not matter to you?

How much does what you’ve learned matter to the community?
  - Why does it matter/not matter to the community?
  - Does it matter to anyone else?

When did you last figure something out in the unit?
  - What did you figure out?
  - How did you figure it out?

When did you last feel like you were “doing science?”
  - What were you doing?

How does your teacher help support your learning?

What would you change about the unit to make it better?
Article 2: Teacher Interview Protocols

Interview 1 – Beginning of Pilot

Section A – Background and school context
How did you hear about the pilot?
  Why did you want to be a part of the pilot?
Tell us a little bit about your background and preparation for teaching science.
Tell us a little bit about your school.

Section B – Knowledge and beliefs about students
What are the students like at your school?
What factors most influence how a student learns?
How do you think your students learn best?

Section C – Teaching practices and knowledge
How do you plan your instruction?
  What resources do you use?
When do you adapt materials for use in your classroom?
  What materials do you adapt?
  How do you adapt them?
  Why do you adapt them?
What typically happens in your class?
What do you know about the Next Generation Science Standards?
  What do you think are the biggest challenges the NGSS presents?
  How prepared do you feel to meet those challenges?

Section D – Unit implementation
How are you finding the ecosystems unit so far?
How are students finding the ecosystems unit so far?
How would you describe the unit to a colleague who hasn’t seen it?
What aspects of the Ecosystems unit do you think are most effective?
  What aspects of the unit seem least effective?
What are the biggest challenges you think you’ll encounter in implementing the unit?
  How do you plan to address those challenges?
  Are there any tools you would find especially helpful in meeting those challenges?
What planning and preparation will you do prior to the implementation of the unit?
What planning and preparation will you do during the implementation of the unit?
How is this planning similar or different than what you typically do?
Do you have plans to adapt the unit from how it’s written? If so, how? And why are these adaptations needed?
What do you anticipate will be your students’ responses to the unit?

Interview 2 – End of Pilot

Section A – Knowledge and beliefs about students
What are the students like at your school?
What factors most influence how a student learns?
How do you think your students learn best?

Section B – Teaching practices and knowledge
How do you plan your instruction?
What resources do you use?
When do you adapt materials for use in your classroom?
What materials do you adapt?
How do you adapt them?
Why do you adapt them?
What typically happens in your class?
What do you know about the Next Generation Science Standards?
What do you think are the biggest challenges the NGSS presents?
How prepared do you feel to meet those challenges?

Section C – Unit Implementation
What did you think of the ecosystems unit?
What did students think of the ecosystems unit?
How would you describe the unit to a colleague who hasn’t seen it?
What did you and the students do during the unit?
What aspects of the Ecosystems unit do you think are most effective?
What aspects of the unit seem least effective?
What were the biggest challenges you encountered while implementing the unit?
How did you address those challenges?
Are there any tools you would have found helpful in meeting those challenges?
Which parts did you end up not enacting, and why?
What adaptations did you make, and why?
How successful were these adaptations?
What challenges do you think there will be in bringing a new Biology curriculum to teachers in the rest of the district?
What do you think are the best ways to address these challenges?
Appendix C

Article 3: Teacher Online Survey 1 (Pre/Post)

The purpose of this survey is to better understand and evaluate the efficacy and ease of use of the NGSX platform, the activities, tools, and resources provided in the Teacher Study Group Pathway.

We expect this part of the survey to take 30-40 minutes. Please just do the best you can. Don’t worry about being right or wrong. We simply want to know how you are thinking!

1. Full Name

2. What is your gender?
   - Male
   - Female

3. What study group are you in?

4. In which school and district do you teach or work as a science coach or administrator?

5. Are you a classroom teacher, science coach, or administrator?
   - Classroom teacher
   - Science coach or administrator (Please describe your position) ______________________

6. If you are a classroom teacher, what do you teach? (Select all that apply)
   - Elementary
   - Middle School Science
   - High School Biology
   - High School Chemistry
   - High School Environmental Science
   - High School Earth and/or Space Science
   - High School Physics
   - Other (please specify) ______________________

7. What age group are you certified to teach? (Select all that apply)
   - K - 5
   - 6 - 8
   - 9 - 12
   - Do not hold a certificate
   - Other (Please specify) ______________________

*Your ideas about air - The Vacuum Cleaner*
In this part of the survey we want to know how you are thinking about the science of air. Please just do the best you can. Don’t worry about being right or wrong. We simply want to know how you are thinking.

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

9. 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?

- Particles in a regular pattern
- Particles filling the space in a regular pattern
- Random particles in uniform material
- Random particles in nothing
- Particles filling the space randomly

Comments (Optional)
Felicia's Volleyball

10. 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?

- The weight increases
- The weight decreases
- The weight stays the same

Explain your thinking.

Joe and the Syringe

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.

11. Which of the following statements do you agree with?

- Joe won’t be able to push the plunger into the syringe, because it is full of air.
- Joe will be able to push the plunger all the way in, because there’s nothing in the syringe.
- Joe will be able to push the plunger only part-way in, because the farther the plunger goes in, the harder the air will push back.
- Joe will be able to push the plunger all the way in, because the air inside the syringe can’t oppose the force of the mass of the plunger accelerated by Joe’s push.
12. Which of the following statements best explains your reasoning? When Joe tries to push the plunger into the syringe...
- Because it’s still the same gas, the air inside the syringe will not change.
- Pushing on the plunger doesn’t change the size or mass of the gas particles, so the properties of the air inside the syringe won’t change.
- The net effect of pushing on the plunger is that the individual gas particles are compressed.
- The gas particles don’t change, but the distance between them will get smaller.

Fred’s Basketball

Fred wants to practice dunking the basketball – so he wants the ball to be lighter. He decides to add some helium to his ball.

13. When he pumps the extra helium into his ball – what will happen?
- The ball will be lighter, but not enough to matter.
- The ball will be easier to dunk, because it is lighter.
- The ball will get heavier.
- The weight of the ball will stay the same.

14. Which statement below best explains your answer?
- The ball has more inside it.
- Helium makes things lighter.
- The ball is still the same size.
- Helium has no mass.

Your feelings about your own science teaching

The following questions refer to your opinions about your own classroom teaching of science. If you are an administrator, please answer these questions with the teachers you work with in mind.
15. How confident do you feel with respect to teaching science in the ways called for in...

<table>
<thead>
<tr>
<th>...the NRC Framework for K-12 Science Education (Framework)?</th>
<th>Unfamiliar</th>
<th>Not very confident</th>
<th>Somewhat confident</th>
<th>Confident</th>
<th>Very confident</th>
</tr>
</thead>
<tbody>
<tr>
<td>...the Next Generation Science Standards (NGSS)?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Comments (Optional)

16. How closely aligned do you feel the curriculum you use now is with the NRC Framework and NGSS?

<table>
<thead>
<tr>
<th>...the NRC Framework for K-12 Science Education (Framework)?</th>
<th>Not sure</th>
<th>Not aligned</th>
<th>Somewhat aligned</th>
<th>Fairly aligned</th>
<th>Very aligned</th>
</tr>
</thead>
<tbody>
<tr>
<td>...the Next Generation Science Standards (NGSS)?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Comments (Optional)
17. How well do you feel prepared to support students in each of the following science and engineering practices?

<table>
<thead>
<tr>
<th></th>
<th>Not adequately prepared</th>
<th>Somewhat prepared</th>
<th>Fairly well prepared</th>
<th>Very well prepared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asking questions and defining problems</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Developing and using models</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Planning and carrying out investigations</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Analyzing and interpreting data</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Using mathematics and computational thinking</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Constructing explanations and designing solutions</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Engaging in argument from evidence</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Obtaining, evaluating, and communicating information</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

Comments (Optional)

18. About how long did this survey take you to complete?

○ 10 - 19 minutes
○ 20 - 29 minutes
○ 30 - 39 minutes
○ 40 - 49 minutes
○ 50 minutes or more

Comments (Optional)
Article 3: Teacher Online Survey 2 (Pre/Post)

Your ideas about teaching

This is the second part of the Pre/Post Survey. Please be as honest as you can in answering these questions. There are not really any right or wrong answers. We simply want to know how you are thinking!

1. Full Name

2. Which study group are you in?

Your feelings about your own science teaching

The following questions refer to your opinions about your own classroom teaching of science. If you are an administrator, please answer these questions with the teachers you work with in mind.

3. How well prepared do you feel to do each of the following as part of your instruction? (H73+)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Not adequately prepared</th>
<th>Somewhat prepared</th>
<th>Fairly well prepared</th>
<th>Very well prepared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anticipate difficulties that students may have with particular science ideas and procedures</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Find out what students thought or already knew about the key science ideas</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Implement prescribed lesson plans</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Monitor student understanding</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Assess student understanding</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Support classroom discussions drawing on student ideas</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>
Comments (Optional)

4. The following statements relate to your beliefs about how TEACHERS should use hands-on/laboratory activities in the classroom. For each of the statements, state the degree to which you agree or disagree.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly disagree</th>
<th>Moderately disagree</th>
<th>Slightly disagree</th>
<th>Slightly agree</th>
<th>Moderately agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teachers should ask students to support their conclusions about a science concept with evidence. (TB7)</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Teachers should have students do interesting hands-on activities, even if the activities do not relate closely to the concept being studied. (TB13)</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Teachers should provide students with the outcome of an activity in advance so students know they</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>
are on the right track as they do the activity. (TB16)

When students do a hands--on activity and the data don't come out right, teachers should tell students what they should have found. (TB19)

Teachers should explain an idea to students before having them consider evidence that relates to the idea. (H39)

Comments (Optional)

5. The following statements relate to your beliefs about how STUDENTS should use hands-on/laboratory activities in the classroom. For each of the statements, state the degree to which you agree or disagree.

<table>
<thead>
<tr>
<th>Hands-on/laboratory activities</th>
<th>Strongly disagree</th>
<th>Moderately disagree</th>
<th>Slightly disagree</th>
<th>Slightly agree</th>
<th>Moderately agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>
SUPPORTS FOR IMPLEMENTATION OF NGSS

used primarily to reinforce a science idea that the students have already learned. (H39i)

Students should rely on evidence from classroom activities, labs, or observations to form conclusions about the science concept they are studying. (TB3)

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. (TB8)

Students should use evidence to evaluate claims about a science concept made by other
students. (TB12)
Students should consider evidence that relates to the science concept they are studying. (TB18)
Students should know what the results of an experiment are supposed to be before they carry it out. (TB20)
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. (TB21)

Comments (Optional)

Your Beliefs about Structure of Classroom Instruction

The following questions refer to your beliefs about how science should be taught in classrooms.

6. The following statements relate to your beliefs about how classroom instruction is organized or structured. For each of the statements, state the degree to which you agree or disagree.
<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly disagree</th>
<th>Moderately disagree</th>
<th>Slightly disagree</th>
<th>Slightly agree</th>
<th>Moderately agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>It is better for science instruction to focus on ideas in depth, even if that means covering fewer topics. (H39c)</td>
<td>⬜️</td>
<td>⬜️</td>
<td>⬜️</td>
<td>⬜️</td>
<td>⬜️</td>
<td>⬜️</td>
</tr>
<tr>
<td>Students should be provided with the purpose for a lesson as it begins. (H39d)</td>
<td>⬜️</td>
<td>⬜️</td>
<td>⬜️</td>
<td>⬜️</td>
<td>⬜️</td>
<td>⬜️</td>
</tr>
<tr>
<td>At the beginning of instruction on a science idea, students should be provided with definitions for new scientific vocabulary that will be used. (H39e)</td>
<td>⬜️</td>
<td>⬜️</td>
<td>⬜️</td>
<td>⬜️</td>
<td>⬜️</td>
<td>⬜️</td>
</tr>
<tr>
<td>Most class periods should conclude with a summary of the key ideas addressed. (H39k)</td>
<td>⬜️</td>
<td>⬜️</td>
<td>⬜️</td>
<td>⬜️</td>
<td>⬜️</td>
<td>⬜️</td>
</tr>
<tr>
<td>At the beginning of lessons, teachers should 'hook' students with stories, video clips, demonstrations or other concrete events/activities</td>
<td>⬜️</td>
<td>⬜️</td>
<td>⬜️</td>
<td>⬜️</td>
<td>⬜️</td>
<td>⬜️</td>
</tr>
</tbody>
</table>
in order to focus student attention. (TB14)

Comments (Optional)

7. The following statements relate to your beliefs about how students’ ideas should be dealt with in the classroom. For each of the statements, state the degree to which you agree or disagree.

<table>
<thead>
<tr>
<th>Teachers should provide students with opportunities to connect the science they learn in the classroom to what they experience outside of the classroom. (TB6)</th>
<th>Strongly disagree</th>
<th>Moderately disagree</th>
<th>Slightly disagree</th>
<th>Slightly agree</th>
<th>Moderately agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teachers should provide students with opportunities to apply the concepts they have learned in new or different contexts. (TB11)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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. (TB15)

Students should have opportunities to connect the concept they are studying to other concepts. (TB17)

Comments (Optional)

Your goals for this year

8. Every teacher has goals for each of the classes that they teach and what they want their students to have learned by the end of the course or year. By the end of the course/year, how much emphasis will each of the following goals receive? (H45a-g)

<table>
<thead>
<tr>
<th></th>
<th>None</th>
<th>Minimal emphasis</th>
<th>Moderate emphasis</th>
<th>Heavy emphasis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memorizing science</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
</tr>
</tbody>
</table>
vocabulary and/or facts
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
Learning test taking skills/strategies

Are there any other major goals that you have that are not currently listed here?

Your ideas about developing and using models

The NRC Framework and NGSS refer to the scientific practice of "developing and using models." The next questions ask about your ideas about this practice.

9. Describe what you would consider to be a good example of an activity in which the teacher supports students in developing and using models. What are students being asked to do? (This may be something you actually do, but does not have to be.)

10. What do you see as the purpose of this activity?

11. Is there an example from your own teaching that is similar to this approach to having students develop and use models? If so, describe it here, and explain how it fits or differs.

Your ideas about argumentation

The NRC Framework and NGSS refer to the scientific practice of "engaging in argument from evidence." The next questions ask about your ideas about this practice.
12. Describe what you would consider to be a good example of an activity in which the teacher supports students in argument from evidence. What are students being asked to do? (This may be something you do, but does not have to be.)

13. What do you see as the purpose of this activity?

14. Is there an example from your own teaching that is similar to this approach to having students engage in argument from evidence? If so, describe it here, and explain how it fits or differs.

*Your ideas about classroom discussion*

15. Describe what you would consider to be a good example of an activity in which the teacher is supporting students in whole class discussion. (This may be something you do, but does not have to be.)

16. Is there an example from your own teaching that is similar this approach to supporting a whole class discussion? If so, describe it here, and explain how it fits or differs.

17. What are the characteristics of whole class discussion that you look for to decide if the activity is going well or is productive?

*Your experience with NGSX (Post Only)*

Finally, we have a few questions about your experience with the NGSX pathway.

18. What are the one or two most important things you feel you learned in NGSX?

19. What do you still need to learn more about before taking NGSS into your own classroom?

20. What suggestions do you have for improving NGSX?

21. About how long did this survey take you to complete?
   - 10- - 19 minutes
   - 20 - 29 minutes
   - 30 - 39 minutes
   - 40 - 49 minutes
   - 50 minutes or more

*Article 3: Teacher Online Survey 3 (Mid-Point)*

1) Think back to when you first heard about the NGSX and decided to participate. In what ways has your experience so far been similar to what you hoped it would be? How has it been different?
2) In what ways has NGSX supported your learning about the Framework and the NGSS?

3) In what ways could the first four units have been improved, to better support your learning?

4) A broader goal of NGSX is to serve as a tool to help prepare you and your colleagues to implement NGSS. Imagine you are in Jeff’s or Linda’s shoes, responsible for accomplishing this task, what would you do?

5) What do you think you can or should do, in your own school, to learn more and help your colleagues learn about NGSS?

**Article 3: Teacher Interview Protocol**

*Introduction*

The purpose of this interview is to get your perspectives on NGSS and your experience of NGSX. We’ll ask some questions about how you and your colleagues see NGSS fitting in with other goals and initiatives of your school and the district. We’ll also ask you some questions about your plans to implement NGSS related practices.

*Teachers’ Ideas about NGSS and their participation in NGSX*

Where did you first became aware of the *Next Generation Science Standards*? What was your first impression or thought about them?

NGSS foregrounds the teaching of core ideas in science, practices, and crosscutting concepts. In your view, what are the most important “core ideas” you teach? What makes them important?

In your view, what are the most important science practices for your students to master? What makes them important?

If another teacher were to ask you what NGSX is all about, what would you say?

Has your participation in NGSX changed your knowledge of, or the way you think about science?

*If no* What experiences have you had that have changed the way you think about science?

*If yes* Tell me a little about what kinds of changes you have experienced and tell me how those changes have occurred--what has supported them or caused them? *(Let teacher answer this then probe for big ideas in general and changes in thinking about those.)*
What aspects of the NGSX study group process have been:
Most helpful to you in learning about NGSS? Why or how?
Least helpful to you in learning about NGSS? Why or how?
Most helpful to you in learning about developing and using models as a science practice? Why or how?
Least helpful to you in learning about developing and using models as a science practice? Why or how?

Are there colleagues or district leaders participating in NGSX who’ve been particularly helpful in guiding your understanding of NGSS? If so, how have they been helpful to you?

If you could improve NGSX, what would you do?

Teachers’ Use of Ideas and Tools from NGSX to Design or Adapt Instructional Materials

In general, what are the sources you consult when you decide what to teach?
Are these sources ones that were given to you? If so, by whom?
Did you develop these materials? Did you develop these with a curriculum team?
Why did you choose to use these sources over others?

What kinds of materials and activities do students in your class use that are consistent with what’s demanded in NGSS? How are they consistent?

What kinds of materials and activities are inconsistent or might need to be modified to reflect the demands of NGSS?
How might they need to be modified?
How prepared do you feel to adapt those materials and activities to align with NGSS?

Have you designed (or contributed to the design of) activities or curriculum materials that are intended to help students meet performance expectations in NGSS?
If so, what kinds of activities or materials have you designed?
How are they different from the activities or materials you’ve used in the past?

Did NGSX help you to identify ways to support students from diverse backgrounds? If so, how?
If not, what is needed to support the diversity of students in your class? (Explain, if needed, that by diversity we mean intellectual, physical, economic, racial, ethnic, linguistic, or gender differences of any type.)

Issues or Concerns That Prompt Individual or Collective Sensemaking about NGSS

What most excites or interests you about NGSS?

What are some of the concerns about NGSS you have discussed with colleagues who are part of the study group? Why are these concerns? How (if at all) can these concerns be addressed?

Besides the study group members, are there other colleagues with whom you’ve discussed
concerns regarding NGSS? If so, what are those concerns?

What are some concerns you have that you’ve thought about but haven’t voiced to others in the study groups or to other colleagues? Why are these concerns to you? How (if at all) can these concerns be addressed?

*Note: If assessment concerns have not been raised, ask whether they perceive assessment to be a support or barrier to implementing NGSS.*

What do you think your colleagues at your school will think about NGSS? What aspects of NGSS will resonate with them? Will seem contrary to what they expect students to know and be able to do? Will be confusing?

How consistent is NGSS with what leaders in your school (e.g., principal, AP, or LEAP evaluator) expects to see when he or she visits your classroom?
- How would you explain to him or her the consistencies or differences?
- How might your principal’s ideas about good teaching affect your decision to engage students in developing and using models in science?

How consistent is NGSS with what your students expects to encounter in science class?
How do you think you might prepare them the first week of class next year that’s different from how you prepare students now?

How might you anticipate parents to respond to NGSS? How might you describe what NGSS is all about to them?

*Perceptions of the Gap between Current Instruction and NGSS-Aligned Instruction*

The Next Generation Science Standards and the State Academic Standards (SAS) are two different sets of standards.
- What would you say is similar about them? What’s different?
- Are there any conflicts between the two?
- What did you hear people in the NGSX videos claim was new about the NGSS?
- Which of those claims did you agree with and why?

What are some instructional practices that you use with students that you plan to maintain if the district were to adopt NGSS? Why are these important to maintain?

What are some instructional practices you might introduce if the district were to adopt NGSS? Why would these practices be important to maintain? What kinds of supports would you want the district or your school to provide, to make those changes to your practice?

What kinds of changes do you think your colleagues will need to make to their instruction aligned to NGSS? How should the district or your school go about preparing them to make those changes?
Plans to Implement Instruction to Engage Students in Science Practices

Has your participation in NGSX changed the way you teach science?
[If no] What experiences have you had that have changed the way you teach science?
[If yes] Would you give some examples? *(Try to keep the teacher focused on changes in their teaching practices. Changes in student thinking will be addressed on a following question.)*

*(Let the teachers respond by providing their own examples concerning changes in their teaching before you follow-up with the probes. For topics from the probe that the teachers address spontaneously, you might just ask if they would like to say any more...use your own judgment based upon how much was already said.)*

Would you talk about your use of models in science this year? Has that been different compared to previous years?

Would you talk about your use of classroom discussions in science this year? Has that been different compared to previous years?

If your teaching has changed, what, if anything, has surprised you about students’ responses to your teaching? How, if at all, did their responses confirm your expectations?

Based upon your experiences as a teacher taking part in NGSX, what advice would you give to another teacher who wanted to make changes to meet the new student expectations of NGSS?
   What questions, obstacles, or surprises might that teacher encounter?
   How might the teacher address those concerns?