Next Generation Science Standards: A National Mixed-Methods Study on Teacher Readiness

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Next Generation Science Standards (NGSS) science and engineering practices are ways of eliciting the reasoning and applying foundational ideas in science. As research has revealed barriers to states and schools adopting the NGSS, this mixed-methods study attempts to identify characteristics of professional development (PD) that will support NGSS adoption and to improve teacher readiness. In-service science teachers from across the nation were targeted for the survey and responses represented 38 states. Research questions included: How motivated and prepared are in-service 7–12 teachers to use NGSS science and engineering practices? What is the profile of 7–12 in-service teachers who are motivated and feel prepared to use NGSS science and engineering practices? The study revealed that teachers identified engineering most frequently as a PD need to improve their NGSS readiness. High school teachers rated themselves as more prepared than middle school and all teachers who use Modeling Instruction expressed higher NGSS readiness. These findings and their specificity contribute to current knowledge, and can be utilized by districts in selecting PD to support teachers in preparing to implement the NGSS successfully.

On April 9, 2013, the final draft of the Next Generation Science Standards (NGSS) was published. This document, the result of collaboration between Achieve, Inc. and 26 lead states, seeks to provide students nationwide with an internationally benchmarked education by articulating crosscutting and deeply conceptual science performance expectations (NGSS, 2013). Despite the final publication of NGSS and the commitment of lead states to adopt the standards, little exists in firm implementation strategies and timelines. Research has already identified barriers to NGSS implementation such as the limited instructional time currently devoted to science, the lack of physical resources for effective science education, and insufficient preparation of elementary teachers (Trygstad, Smith, Banilower, & Nelson, 2013). However, teacher preparedness is a concern at all levels as some current models of teaching (fact and lecture based) are incapable of satisfactorily addressing the mandates of NGSS, which emphasize conceptual and exploratory learning (Cooper, 2013). Thus, there is a national urgency to identify the kind of professional development (PD) that will best prepare teachers to meet the challenges of the NGSS. It may require a considerable investment of resources to develop the appropriate materials and tools to support both teachers and students (Wilson, 2013). We must realign the resources spent on PD with the demands teachers will face in an NGSS classroom, and also conduct the research required to learn from it.

The present study sought to meet the need for research on readiness and motivation of middle and high school in-service teachers to apply NGSS science and engineering practices in their classrooms. We also attempt to identify the characteristics of a teacher who feels well prepared to implement NGSS, to identify areas of content weakness and professional development needs, and to use the information we have learned from this survey's results to provide recommendations for teacher training as lead states begin the NGSS adoption process.

Literature Review

Not all teachers are receptive to educational innovations (Abrami, Poulsen, & Chambers, 2004). Some embrace the innovation with great enthusiasm and incorporate it into their teaching while others discard it and return to traditional teaching practices after only a few attempts (Lam, Cheng, & Choy, 2010). In order for teachers to persist in their efforts to adopt new strategies, they need to have the expectation that they will succeed (Abrami et al., 2004).

Academic Standards

To understand the relevance, potential implications, and likely trajectory of the NGSS implementation, it is first important to view academic standards within the more general historical context of standards-based educational reform. This history of academic standards as they are currently understood has its roots in a push for educational reform that began in the early 1980s, continued in strength through the 1990s, and continues to this day (Zuzovsky & Libman, 2006). This surge in the popularity of standards-based educational reform is often thought of as originating with the 1983 publication of *A Nation at Risk* (The National Commission on Excellence in Education, 1983) and the resulting nationwide panic over the state of

American education and the high school graduate's ability to function as a productive member in a national and international society (Vogler & Virtue, 2007). Problems of schooling were considered to be due to low accountability within the educational system. Standards made educational goals more transparent and directly indicate what is expected of stakeholders, namely teachers and students (Miskel & Ogawa, 1988). By 1989, curriculum standards were developed in math, and other subject areas soon followed suit (Delandshare & Petrosky, 2004).

Evolution of standards (state and national) in the STEM disciplines. NGSS is a set of science standards. Science and its fellow technology, engineering, and mathematics (STEM) disciplines are, and have been for a least a decade, the focus of tremendous concern and reform effort from educators nationwide (Dugger, 2010; Sanders, 2009). The reasons for this are varied. The concern that the United States is falling behind other nations of the world in STEM areas, and that this lack could potentially manifest as economic disaster in the future (Sanders, 2009) has resulted in an influx of federal funding for STEM education and research, and the encouragement of organizations (e.g., National Science Foundation, or NSF) to pursue this research (Dugger, 2010).

Over the past two decades, state science standards have been based on the 1996 *National Science Education Standards* (published by the National Research Council) and the 1993 *Benchmarks for Scientific Literacy* (Labov, 2006). Although these national documents do not represent standards adopted by all states, they aid in the development of state frameworks though this translation and adoption process has often proven difficult (Tanner & Allen, 2002). Subsequently, the No Child Left Behind Act (NCLB, 2002) was signed into law. According to the U.S. Department of Education (2002), this Act was meant to change the culture of American education by mandating achievement and results. These results are monitored via mandatory testing for all students enrolled in grades three through eight. NCLB requires that students be tested in reading language arts, mathematics, and science.

Although science is a subject for which NCLB mandates annual testing, the testing is not nationalized. NCLB gives states the responsibility to set standards, support classroom instruction, ensure qualified teachers, and create assessment tools to measure progress (Marx & Harris, 2006). As such, state-designed and implemented standards are generally related in content and form, though the degree of this interrelation is variable. It is possible that the need to create standards that can be measured by high-stakes testing, drives states toward producing standards that focus on facts rather than on difficult-to-measure skills such as deep thinking and conceptual understanding of the underlying processes of science and STEM subjects (Marx & Harris, 2006). Some claim that high-stakes testing at the secondary level prompts teachers to cover massive amounts of information, and so moving beyond an educational experience based in anything more that rote memorization is difficult (Vogler & Virtue, 2007).

NCLB and high-stakes testing have been criticized by both educators and educational researchers. One persistent criticism is that the high-stakes nature of these federally mandated tests promotes teaching to the test. (Cawelti, 2006; Flinders, 2005; Guilfoyle, 2006). Science standards are to some degree political documents, co-created by committees of individuals representing a broad spectrum of educational and scientific interest groups. A standards document produced in this way represents a group's best effort to find consensus about the essential concepts to be learned within scientific subdisciplines. However, these standards cannot ensure that the concepts will receive similar treatment in all classrooms.

The developmental trajectory of NGSS. In the summer of 2011, a writing team of 41 individuals began work on the first draft of the NGSS. As the effort was intended to be a collaborative effort of various stakeholders, the document was released for public review multiple times, and the writers were charged with being responsive to the feedback these drafts received. On April 9, 2013, the finalized NGSS document was released.

NGSS describe what all students should know and be able to do by the time they graduate from high school. NGSS are based on learning progressions of core ideas in the discipline, concepts that cut across disciplines and practices that will allow students to use their disciplinary knowledge in meaningful ways. An important advance from earlier standards from the National Research Council (NRC, 1996), NGSS Science and Engineering Practices are clearly identified not as separate learning goals that define what students should know about the process of science, but rather as ways of identifying the reasoning behind, discourse about, and application of the core ideas in science (Reiser, Berland, & Kenyon, 2012).

The science and engineering practices outlined in the NGSS are: asking questions and defining problems, developing and using models, planning and carrying out investigations, analyzing and interpreting data, using mathematics and computational thinking, constructing explanations and designing solutions, engaging in argument from evidence, and obtaining, evaluating, and communicating information (Achieve, Inc., 2013).

The process of creating the NGSS was driven by 26 lead states. These states contributed resources and support to the development process, and are expected to be trailblazers in the adoption and implementation of the NGSS. The choice to implement curricula and the form these curricula will take is consequently at the discretion of individual states.

NGSS and Modeling Instruction

One cornerstone of NGSS (Achieve, Inc., 2013) is the use of eight core science and engineering practices, which are identified above. These practices are at the foundation of Modeling Instruction, a research-based pedagogy for science education, developed in the 1980s.

Modeling Instruction integrates a student-centered teaching method with a model-centered curriculum (Hestenes, 1996; Jackson, Dukerich, & Hestenes, 2008). It applies structured inquiry techniques to teaching basic skills in mathematical modeling, proportional reasoning, quantitative estimation, and data analysis, which contribute to the development of critical thinking, including the ability to formulate hypotheses and evaluate them with rational argument and evidence.

Modeling pedagogy has three components: the models, the Modeling Cycle, and classroom discourse management (Hestenes, 1996). An understanding of these components is the pedagogical content knowledge (Shulman, 1986) needed for successful classroom implementation. A model is a representation of structure—a conceptual representation of a real thing (Hestenes, 1987). According to Johnson-Laird (1996), mental models have a structure that corresponds to the structure of what they represent. He defines perception as the transformation of sensory information into a mental model, and defines thinking as the manipulation of mental models. The models around which learning is centered in modeling are fundamental relationships among quantities that form the content core of a discipline (e.g., physics), and these models are developed by students into tools for making sense of physical reality—for making predictions and answering questions.

Modeling is an activity. Based on Karplus' Learning Cycle (Karplus, 1977), the Modeling Cycle (Hestenes, 1987) is a three-phase process: (a) model construction, which takes place in the context of a paradigm lab that uncovers a relationship between two physical quantities at the beginning of each instructional unit, (b) model validation, in which the student refines the basic model that he or she has constructed by testing it in different initial conditions, and (c) model deployment, in which the student uses the model to solve problems from a variety of contexts. This is analogous to the model-of-model for progression (Streefland, 1985; Treffers, 1987; Van den Heuvel-Panhuzen, 2003) described by Dutch Realistic Mathematics Education researchers who characterize models as bridging objects from informal to formal reasoning.

Others have contributed to current understanding of how students develop and use models in K–12 classrooms. Modeling research has focused on argumentation in science education (Bottcher & Meisert, 2011; Passmore & Svoboda, 2012), the role of models and analogies in science education (Coll, France, & Taylor, 2005), software scaffolds supporting modeling practices (Fretz et al., 2002), model-based inquiry (Passmore, Stewart, & Cartier, 2009), integrating conscious and intuitive knowledge (Cheng & Brown, 2010), and constructing and revising models in the science classroom (Krajcik & Merritt, 2012). Numerous researchers investigating modeling nationally and internationally have influenced the conceptualization of modeling articulated in NGSS (Schwarz et al., 2009; Windschitl, Thompson, & Braaten, 2008).

Teachers learn Modeling Instruction by participating in a Modeling Workshop—an intensive, three-week 90-hour immersion experience. Teachers participate in laboratory investigations and activities, designing experiments, collecting, analyzing, interpreting data, and engaging in classroom discourse to achieve collective sense-making. It is only by active participation in the discourse that characterizes the Modeling learning that a teacher can become an effective manager of modeling discourse in his or her own classroom.

The Modeling Instruction Program has been in existence since 1990. From its initial beginnings in college and high school physics, it has spread across the science disciplines into chemistry, biology, physical science, and middle school (integrated) science. Quantitative evidence supporting the impact of Modeling Workshops has been established through study undertaken as part of the Modeling Workshop Project evaluation and the U.S. Department of Education has identified Modeling Instruction as one of two Exemplary K–12 Science Programs.

Study Overview

This study examines in-service teacher motivation to adopt NGSS science and engineering (S&E) practices and their feelings of readiness to implement these practices in their classrooms. We attempt to discern the characteristics of teachers who feel well prepared to implement NGSS practices and could potentially become mentors for their peers in the NGSS adoption process. In particular, we explore the link between those who identify themselves as

"Modelers" (i.e., practitioners of the Modeling Method of Instruction and NGSS receptiveness and readiness).

Survey data for a pilot study were collected from a group of 45 middle and high school science teachers from four suburban school districts who were participating in a Math Science Partnership PD program to develop skill in using NGSS science and engineering practices. Data from their responses revealed that these science teachers were motivated to use NGSS science and engineering practices, particularly those trained in the use of Modeling Instruction. The pilot study instrument served as the foundation for the larger national online survey developed for administration in March and April of 2013.

Method

Research Design

This study employed a mixed-method approach and thus, the investigator collected, analyzed, and drew inferences from both quantitative and qualitative data in a single study. It involved the assumption that the use of quantitative and qualitative approaches in combination provides greater understanding of the research problem than either approach alone (Creswell & Plano Clark, 2011; Johnson, Onwuegbuzie, & Turner, 2007). The survey had several open-ended questions and comment boxes to enable teachers to provide rich texture around the survey responses. Teachers could further discuss NGSS concerns (e.g., inadequate training) or identify additional support and resources needed for implementation.

The research design included both quantitative and qualitative methods and employed analysis of variance (ANOVA) to determine differences between groups and qualitative analysis to code, categorize, and analyze teacher comments. The assumptions of homogeneity of variance, normality, and independence were tested and met. The survey used a 5-point Likert scale to determine the extent to which teachers felt they needed professional development to prepare for NGSS adoption and to elicit current levels of motivation and perceived readiness to use NGSS science and engineering practices. A test for internal consistency was conducted showing a Cronbach's alpha of .85. This is commonly used as an estimate of the reliability of a psychometric test. An open-ended response section was provided for teachers to volunteer comments with respect to survey items. Research questions that guided the study included:

1. How motivated are in-service 7–12 teachers to use NGSS S&E practices?
   a. What are the differences between middle school and high school teachers?
2. How well prepared do 7–12 teachers feel to use NGSS S&E practices?
   a. What are the differences between middle and high school teachers?
3. Do teachers trained in the use of Modeling Instruction feel more motivated and prepared to use NGSS S&E practices?

The survey collected information on school size and type (public, private, or charter), teacher interest in professional development and the type of PD that appealed to them (e.g., STEM and NGSS training), and socio-demographic characteristics like age, years of teaching, subjects taught, and grade levels taught. Based on pilot study findings, it was hypothesized that years of teaching, types of courses taught, and a prior training in and teaching Modeling Instruction would predict perceived readiness for NGSS.

Participants and Context

In-service teachers from across the nation were invited to complete the survey. These individuals were employed in public, private, and charter schools and represent a national pool of teachers who teach primarily science in middle school and high school: physics or physical science, chemistry, and biology. Teachers who subscribed to science listservs were sent a link to the NGSS Readiness Survey in March of 2013. The survey received 710 teacher responses from across the United States representing 38 states.

Quantitative Data

In order to answer the first research question (How motivated are in-service 7–12 teachers to use NGSS science and engineering practices?), a bank of survey questions was provided that included the eight NGSS S&E practices. To answer the second question (How prepared do 7–12 teachers feel to use NGSS S&E practices?), teachers rated their perceived success in applying the eight practices in the classroom. To answer the third research question (Do teachers trained in the use of Modeling Instruction feel more motivated and prepared to use NGSS S&E practices?), we used statistical analyses to look for group differences.

Data analysis. A 2×2 factorial ANOVA was used to determine specific NGSS practice areas in which Modelers felt more NGSS ready. When there was a statistically reliable overall difference in NGSS readiness scores (for Modeling or grade level), we used a two-tailed, independent samples t-test to identify the direction of this difference. All tests had an alpha level of .05.

Qualitative Data

Teachers were given the opportunity to comment on their NGSS readiness and motivation in a comment box.

Teachers could express any concerns in this area, and as a result, areas of content weakness emerged without prompting. The researcher used the constant comparative method (Glaser & Strauss, 1967) as a conceptualizing method on the first level of abstraction. Teacher comments (open-ended comments) were conceptualized line by line. The initial phase involved conceptualizing all the incidents in the data. The researcher compared data and continually modified and sharpened the growing theory at the same time. Notes were compared to find differences and consistencies between codes (e.g., similarity in meanings), which helped reveal categories. Data were analyzed using a three-step process: data reduction, data display, and conclusion drawing and verification (Miles & Huberman, 1994). Data reduction helped sort, focus, and condense excerpts, which helped organize the data to develop conclusions. Data display enabled review of the reduced data so that conclusions could be drawn. Teachers' excerpts formed the basis for identifying categories, themes, and assertions.

Quantitative Results

Overall, demographic data for the 710 teachers who responded to the NGSS national readiness assessment revealed that about one third held a bachelor's degree (27%), 68% had a master's degree, and 5% had a doctorate degree. Demographic information is shown in Table 1.

The majority of respondents taught physics (32%), followed by "science" (23.5%) (presumably an integrated or general science course), chemistry (20.4%), biology (18.8%), mathematics (2.7%), earth science (2.4%), and physical science (0.2%).

NGSS Teacher Motivation: Middle School and High School Differences

To answer the first research question, "How motivated are in-service 7–12 teachers to use NGSS science and engineering practices"? (and the sub-question, "What are the differences between middle school and high school teachers?"), the study employed a 5-point Likert scale. The scale used a range of 5 = "Highly motivated" to 1 = "Not motivated." High school teachers were reported a higher degree of motivation to use all eight NGSS science and engineering practices than middle school teachers. Results are shown in Table 2.

NGSS Readiness to Use Science and Engineering Practices: Teacher Differences

To answer the second research question, the survey included a 5-point Likert scale to determine NGSS readiness by asking teachers to rate their expectation of success in implementing NGSS science and engineering practices

Table 1
Demographic Data for Survey Respondents

Sex	
Male	43%
Female	57%
Degree	
Bachelor's	27%
Master's	68%
Doctorate	5%
Certification	
Baccalaureate	49%
Post-baccalaureate	47%
None	4%
School Type	
Public	86%
Private	10%
Charter	4%
School Size	
Small	6%
Medium	20%
Large	26%
Very Large	48%
Teaching Assignment	
Physics	32%
Chemistry	20.4%
Biology	18.8%
Other Science	2.6%
Math	2.7%
Science (Middle School)	23.5%
Trained in Modeling Instruction	
Yes	51%
No	49%

Note. Total sample size (710 teachers): 51% Modelers (362 teachers), 49% non-Modelers (348 teachers).

(5 = "Highly certain of success" to 1 = "Cannot expect success"). High school teachers' responses indicated they felt more prepared to implement NGSS science and engineering practices than middle school teachers (Table 3).

NGSS Readiness: an Examination of Modelers and Non-Modelers

Of the respondents, 51% (362 teachers) indicated they used the Modeling Method of Instruction (indicated "Yes" on the survey), while 49% were non-Modelers (indicated "No"). The middle school Modelers had been teaching the same number of years (M = 16, SD = .88), as high school Modelers (M = 15.82, SD =.89) and practiced Modeling Instruction in the classroom for the same number of years (M = 5.8, SD = .58) as high school Modelers (M = 6.04, SD

Table 2
NGSS Eight Practices and Motivation: Middle School and High School Teacher Differences

	Middle School Mean (*SD*)	High School Mean (*SD*)
Motivation		
Asking questions and defining problems	4.28 (.717)	4.54* (.647)
Developing and using models	4.32 (.747)	4.57* (.617)
Planning and carrying out investigations	4.24 (.870)	4.44* (.727)
Analyzing and interpreting data	4.31 (.818)	4.62* (.600)
Using math and computational thinking	4.17 (.854)	4.53* (.686)
Constructing explanations and designing Solutions	3.90 (.881)	4.29* (.833)
Engaging in argument from evidence	4.23 (.807)	4.50* (.733)
Obtaining, evaluating, communicating information	4.39 (.720)	4.54* (.614)

* $P < .05$. Total sample size (710 teachers).

Table 3
NGSS Practices and Readiness: Middle and High School Teacher Differences

	Middle School Mean (*SD*)	High School Mean (*SD*)
Teachers would have success in:		
Asking questions and defining problems	4.09 (.763)	4.38* (.684)
Developing and using models	4.05 (.869)	4.30* (.732)
Planning and carrying out investigations	3.99 (.867)	4.21* (.791)
Analyzing and interpreting data	4.10 (.831)	4.45* (.658)
Using mathematics and computational thinking	3.90 (.859)	4.31* (.771)
Constructing explanations and designing solutions	3.53 (.936)	3.98* (.901)
Engaging in argument from evidence	3.99 (.874)	4.34* (.787)
Obtaining, evaluating, and communicating information	4.19 (.818)	4.42* (.684)

Note. Total respondents (710 teachers). Degree of predicted success (5 = highly certain to 1 = cannot expect success).
* $P < .01$.

= .68). Middle school Modelers had participated in an average of 64 hours of Modeling PD; the average high school Modeler had completed 117 hours of Modeling PD as seen in Table 4.

Training in modeling instruction. There are a variety of professional development experiences that provide

Table 4
Modeler Demographics

	Middle School Modelers Mean	High School Modelers Mean
Hours/Modeling workshops	64	117
Years using modeling instruction	5.8	6
Years of teaching	16	15.87

Note. Modeling respondents (362 teachers).

teachers with training in the Modeling Method of Instruction, from one hour after school sessions, or four to eight-hour sessions at professional conferences, to multi-week Modeling Workshops. Full Modeling Workshops are typically 60–90 hours in length (two to three weeks). This sample of Modelers' median of 90 hours indicates that the typical respondent attended a 90-hour workshop. While the high school Modelers, on average, attended a three-week workshop, the middle school Modelers attended a two-week workshop.

NGSS Motivation: Modelers and Non-Modelers

To answer the third research question, "Do teachers trained in the use of Modeling Instruction feel more motivated and prepared to use NGSS science and engineering practices?" Modelers expressed more motivation to use NGSS S&E practices than non-Modelers, and the difference was significant for all items ($P < .01$) as seen in Table 5.

NGSS Performance: Modelers and Non-Modelers

Those who use Modeling Instruction rated themselves as better prepared to utilize NGSS science and engineering practices than non-Modelers, and the differences were significant for all eight NGSS practices ($P < .05$). Teacher perceptions of NGSS readiness are shown in Table 6.

Modelers rated themselves as better prepared to implement NGSS science and engineering practices, including "Constructing explanations for science and designing solutions for engineering" reflected in the means for Modelers ($M = 4.10$, $SD = .866$) and non-Modelers ($M = 3.84$, $SD = .954$). In addition to probing for readiness to utilize the NGSS practices, the survey included one item that specifically elicited readiness to incorporate engineering problem solving into science instruction. Modelers felt more prepared for "Effectively using engineering problems to help students understand science concepts" than the non-Modelers, and the difference was significant.

Grade Levels and Modeling: Differences Between Groups

Results from the ANOVA showed that there were no statistically reliable interactions between Modeling and

Table 5
How Motivated Are Teachers Who Model Versus Those Who Don't Model?

	Modelers Mean (*SD*)	Non-Modelers Mean (*SD*)
I am motivated to:		
Ask questions and define problems	4.58 (0.616)	4.38* (0.692)
Develop and use models	4.69 (0.545)	4.14* (0.744)
Plan and carry out investigations	4.60 (0.613)	4.29* (0.824)
Analyze and interpret data	4.67 (0.567)	4.35* (0.699)
Use math and computational thinking	4.51 (0.692)	4.27* (0.814)
Construct explanations, design solutions	4.38 (0.780)	4.09* (0.893)
Engage in argument from evidence	4.57 (0.672)	4.32* (0.797)
Obtain, evaluate, and communicate information	4.59 (0.585)	4.41* (0.682)

Note. Total respondents (710 teachers): 51% Modelers (362 teachers), 49% non-Modelers (348 teachers).
* $P < .01$.

Table 6
Success in NGSS Practices: Modelers Versus Non-Modelers

	Modelers Mean (*SD*)	Non-Modelers Mean (*SD*)
Teachers would have success in:		
Asking questions and defining problems	4.38 (0.691)	4.26* (0.752)
Developing and using models	4.37 (0.723)	4.11* (0.794)
Planning and carrying out investigations	4.24 (0.794)	4.09* (0.823)
Analyzing and interpreting data	4.47 (0.653)	4.27* (0.756)
Using math and computational thinking	4.38 (0.722)	3.90* (0.039)
Constructing explanations for science and designing solutions for engineering	4.10 (0.866)	3.84* (0.954)
Engaging in argument from evidence	4.38 (0.791)	4.11* (0.837)
Obtaining, evaluating, and communicating information	4.44 (0.682)	4.30* (0.752)
Effectively using engineering problems to help understand science concepts	3.65 (0.969)	3.47* (1.018)

Note. Degree of predicted success (5 = highly certain to 1 = cannot expect success). Total sample size (710 teachers): 51% Modelers (362 teachers), 49% non-Modelers (348 teachers).
* $P < .05$.

grade level for any of the eight selected NGSS practices. That is, the effect of Modeling does not depend on grade level. Thus, we would expect to find reliably higher means for Modelers in both middle and high school teachers. The researchers classified teachers who indicated that they taught in grades seven and eight as teaching at the "middle school" level and those teaching in grades nine, ten, eleven, and twelve as teaching at the "high school" level.

Modelers in middle school and in high school also rated themselves as more "prepared" to implement the NGSS science and engineering practices in five of the eight practices: Developing and using models (NGSS S&E #2), analyzing and interpreting data (NGSS S&E #4), using mathematics and computational thinking (NGSS S&E 5), constructing explanations and designing solutions (NGSS S&E #6), and engaging in argument from evidence (NGSS S&E #7). Modelers from middle school and high school had similar results in developing and using models and using math and computational thinking. Grade level differences are shown in Table 7.

In order, by NGSS practices: High school Modelers rated their NGSS readiness reliably higher ($M = 4.40$, $SD = .73$) than did high school non-Modelers ($M = 4.20$, $SD = .72$) in developing and using models ($P < .001$). High school Modelers felt better prepared ($M = 4.51$, $SD = .64$) than did high school non-Modelers ($M = 4.36$, $SD = .67$) in analyzing and interpreting data ($P = .01$). High school Modelers also had higher scores ($M = 4.42$, $SD = .71$) than did non-Modelers ($M = 4.17$, $SD = .83$) in using mathematics and computational thinking ($P < .001$). Finally, High school Modelers also rated themselves as more prepared in constructing explanations and designing solutions ($P = .01$) than non-Modelers.

Qualitative Results

Elements Needed to Facilitate NGSS Adoption

Qualitative comments indicate that although most teachers are positive about NGSS, they are anxious about inadequate training, limited instructional time, and lack of resources, all barriers to implementation. Teachers' comments in this study echoed impediments previously identified in a study of elementary teachers, such as insufficient preparation, limited instructional time devoted to science, and the lack of physical resources for effective science education (Trygstad et al., 2013). In addition to fears about the implementation, the comments (commenters' names have been replaced by pseudonyms in the sections below) also revealed that many teachers considered the standards to be too complex in some case exceeding the knowledge and training of the educators who would be expected to teach the content mandated.

Professional development needed. Although at first glance it appears that most teachers rate themselves as reasonably competent to incorporate NGSS S&E practices into their teaching, the accompanying comments by

Table 7
Middle and High School: Modelers and Non-Modeler Differences

Group	High School Non-Modeler Mean (*SD*)	High School Modeler Mean (*SD*)	Middle School Non-Modeler Mean (*SD*)	Middle School Modeler Mean (*SD*)
Asking questions and defining problems	4.34 (.68)	4.41 (.69)	4.0 (.79)	4.1 (.70)
Developing and using models	4.20 (.72)	4.40 (.73)***	3.40 (.93)	4.27 (.67)*
Planning and carrying out experiments	4.14 (.77)	4.26 (.80)	3.95 (.92)	4.10 (.74)
Analyzing and interpreting data	4.36 (.67)	4.51 (.64)**	4.10 (.88)	4.20 (.68)
Using mathematics and computational thinking	4.17 (.83)	4.42 (.71)***	3.84 (.90)	4.15 (.73)*
Constructing explanations and designing solutions	3.92 (.93)	4.20 (.88)**	3.67 (.99)	3.95 (.74)
Engaging in argument from evidence	4.31 (.77)	4.37 (.80)	3.92 (.91)	4.23 (.73)*
Obtaining, evaluating, and communicating information	4.36 (.68)	4.46 (.69)	4.12 (.88)	4.37 (.62)

Note. Degree of predicted success (5 = highly certain to 1 = cannot expect success). Total sample size (710 teachers): 51% Modelers (362 teachers), 49% non-Modelers (348 teachers).
* $P < .05$; ** $P < .01$; *** $P < .001$.

respondents indicate there is concern and in some cases outright anxiety about expectations with respect to their use of and success with S&E practices. Teachers see a need for PD at both middle school and high school levels to facilitate successful NGSS adoption. The majority (84.9%) of teachers in this national sample are interested in pursuing future NGSS PD, but most indicated they would do this only if their school or district was willing to pay for it (70%). Teachers indentified the content focus for PD needed to improve NGSS readiness as follows: engineering (65.6%), technology (50%), science (45.5%), and mathematics (26.2%). Engineering emerged as the content area of greatest need, which is reflected in this excerpt, “I have only a loose grasp on the engineering and design part of the standards and am in desperate need of a concise overview of what they are and how to incorporate them into my teaching” (C. Valdez, survey response, April 13, 2013). Another teacher stated, “The engineering practices in the NGSS standards intrigue me, but I’m a science teacher, not an engineer. I do build projects in my classes to relate the physics to the practical aspects of engineering, but I have no training in this” (S. Rymes, survey response, April 15, 2913). As noted by T. Myers (survey response, April 28, 2013), “As a whole, most teachers will be less comfortable with the science and engineering practices than the disciplinary core ideas. There will be teacher misconceptions on what the performance expectations really are. Without profession development and supports, teachers will not be effective.” A final comment on the critical need for training showed a middle school teacher’s concern, “I think NGSS is a good idea but if middle-school teachers are not trained, it will fail. Current standardized testing pulls the curriculum in different path. I see these two as opposing forces” (A. Boss, survey response, April 27, 2013).

More instructional time and resources needed. Open-ended survey feedback revealed other concerns about NGSS implementation: limited instructional time and resources. A large response rate from middle school teachers (68%) indicated that teachers perceived time as a barrier to successful NGSS implementation. Teachers recognized that cross-cutting concepts were important but realized that reform is needed to allocate more instructional time. One participant (J. Mendez, survey response, April 16, 2013) echoed this sentiment, “More time is needed to teach a course using the inquiry method and NGSS will require more time and resources.” Another teacher talked about adding engineering to his instruction, which will also require more time and materials, “I hope adding engineering doesn’t mean we must always build something. Engineering practices can be met by applying knowledge and skills to real world scenarios. Building and design will cost a lot of money and take up a lot of my current class time” (J. Johnson, survey response, April 10, 2013). The lack of resources and time represent a significant impediment to the NGSS as noted in prior research; in addition to the new standards, teachers will have to contend with not having the necessary facilities, equipment, materials, or time for science teaching (Trygstad et al., 2013).

A theme running throughout the comments reinforced the notion that teachers lacked an engineering background, and many suggested they needed additional training, “I like that the focus has been shifted from ‘learning’ science to ‘doing’ science. Yet, most of us that will be implementing these standards have no engineering background or training and are ill prepared to effectively implement engineering practices” (J. Beck, survey response, April 4, 2013).

Modeling instruction well aligned with NGSS. Teacher comments linked NGSS with Modeling Instruction, as one participant indicated, "Modeling is well aligned with the skills and practices outlined by NGSS" (J. Smith, survey response, April 29, 2013). Another teacher echoed this alignment, reflected in this excerpt, "I'm excited about the NGSS. I am a teacher using the modeling method so I am comfortable with models and scientific thinking in my classrooms" (A. Banks, survey response, April 17, 2013). Comments linking NGSS to Modeling Instruction were frequent in the subset of Modeling respondents, as one noted, "The linkage between NGSS and Modeling is obvious for those who practice Modeling.

Discussion

This study sought to determine how prepared and motivated middle and high school teachers are to adopt and use NGSS S&E practices in their classrooms. Research suggests that there are likely to be significant challenges to overcome for states, districts, and schools that adopt NGSS (Trygstad et al., 2013). Three barriers that have already been identified by prior research are: the need for time, resources, and training. In addition to concerns about limited school resources and instructional time (e.g., the difference between how science is currently taught and what NGSS will mandate), the third area of concern is teacher preparation (Cooper, 2013; Trygstad et al., 2013), which has been examined at both the middle and high school levels in this study. We found that high school teachers who have completed an average of 90 hours of professional development in Modeling Instruction (the typical three-week workshop) feel significantly more motivated and better prepared for NGSS than high school teachers who are non-Modelers. Middle school teachers, with an average of 64 hours of professional development in Modeling Instruction, felt better prepared in a number of NGSS practice areas than non-Modeler middle school teachers. Both high school and middle school teachers identified a need for preparation in engineering content.

Perceived Success in Utilizing NGSS Science and Engineering Practices

Current science teaching practices often emphasize the memorization of facts, yet NGSS emphasizes the primacy of the active construction by students of conceptual knowledge by "doing science" via science and engineering practices. Modeling Instruction shifts the paradigm of how science is taught to a pedagogy that is well aligned with NGSS S&E practices. Teachers trained in Modeling Instruction feel better prepared and more likely to succeed in implementing these practices in their classrooms. Modelers say that they are already routinely incorporating S&E practices into their daily classroom activities.

Limitations

This survey was distributed via a collection of local and national listservs to which middle and high science teachers subscribe. Respondents were self-selected as there was no incentive for survey completion. Therefore, these survey results are generalizable to the population of teachers who would routinely read such a list—teachers who care enough about their teaching and learning to look to their peers for ways to improve their classroom practice.

Implications

Modelers express more motivation and readiness to use NGSS S&E practices. What might this mean to the schools and districts they serve? This teacher community offers a profile of well-prepared, confident teachers who could become leaders in NGSS teacher professional development. In addition, they could be enlisted as peer mentors in schools and districts to help with the transition to the new standards.

As NGSS move toward large-scale adoption and implementation, it is critical that educational leaders nationwide understand what these standards and the changes they portend will mean for the teachers who must work with them. To this end, our study attempts to identify factors affecting implementation and teacher readiness, particularly in the area of science and engineering practices. Our results support and build upon prior research on elementary teachers, adding to the extant literature on NGSS readiness. Similar to the findings of Trygstad et al. (2013), our data indicate a need for focused professional development for both high school and middle school teachers. Among other things, we have found that teachers are concerned about receiving additional training and education in engineering. Teachers also perceived time as a barrier to successful NGSS implementation. Teachers recognized that cross-cutting concepts were important but realized that reform is needed to allocate more instructional time.

We have found significant links between teachers' use of Modeling Instruction and their confidence in using NGSS science and engineering practices. Teachers with training in Modeling Instruction feel more motivated and better prepared to implement NGSS S&E practices in their classrooms. In fact, they are already doing so. Seventy Modeling Workshops held nationwide each summer serve 1,000 physics, chemistry, biology, and physical science teachers at 20–25 host institutions (universities and school districts). This professional development network is a resource for middle school and high school teacher professional development in NGSS S&E practices that is already in place nationwide.

The Modeling teacher community numbers over 7,000 at present. Two hundred Modeling teachers have received training to lead Modeling Workshops. Thus, the excess capacity already exists in the Modeling teacher community to double the number of Modeling Workshops that serve secondary science teachers each summer.

The findings of this study indicate that in-service teachers believe they need training to adequately implement NGSS S&E practices. Those responsible for ensuring successful implementation need to heed this call by teachers.

References

Abrami, P. C., Poulsen, C., & Chambers, B. (2004). Teacher motivation to implement an educational innovation: Factors differentiating users and non-users of cooperative learning. *Educational Psychology*, *24*, 201–216.

Achieve, Inc. (2013). Next generation science standards: Adoption and implementation. Retrieved from http://www.achieve.org/files/NGSS_Workbook_PDF-3.1.13.pdf

Bottcher, F., & Meisert, A. (2011). Argumentation in science education: A model-based framework. *Science Education*, *20*, 103–140.

Cawelti, G. (2006). The side effects of NCLB. *Educational Leadership*, *64*(3), 64.

Cheng, M., & Brown, D. (2010). Conceptual resources in self-developed explanatory models: The importance of integrating conscious and intuitive knowledge. *International Journal of Science Education*, *32*(17), 2367–2392.

Coll, R. K., France, B., & Taylor, I. (2005). The implications from research. *International Journal of Science Education*, *27*(2), 183–198.

Cooper, M. (2013). Chemistry and the next generation science standards. *The Journal of Chemical Education*, *90*(6), 679–680.

Creswell, J. W., & Plano Clark, V. L. (2011). *Designing and conducting mixed methods research* (2nd ed.). Thousand Oaks, CA: Sage.

Delandshare, G., & Petrosky, A. (2004). Political rationales and ideological stances of the standards-based reform of teacher education in the US. *Teaching and Teacher Education*, *20*(1), 1–15.

Dugger, W. E. (2010). *Evolution of STEM in the United States*. Retrieved from http://www.iteaconnect.org/Resources/PressRoom/AustraliaPaper.pdf

Flinders, D. J. (2005). The failings of NCLB. *Curriculum and Teaching Dialogue*, *7*(1/2), 1–9.

Fretz, E. B., Wu, H. K., Zhang, B., Davis, E. A., Krajcik, J. S., & Soloway, E. (2002). An investigation of software scaffolds supporting modeling practices. *Research in Science Education*, *32*(4), 567–589.

Glaser, B. G., & Strauss, A. L. (1967). *The discovery of grounded theory: Strategies for qualitative research*. Chicago: Aldine Publishing Company.

Guilfoyle, C. (2006). NCLB: Is there life beyond testing? *Educational Leadership*, *64*(3), 8.

Hestenes, D. (1987). Toward a modeling theory of physics instruction. *American Journal of Physics*, *55*(5), 440–454.

Hestenes, D. (1996). Modeling methodology for Physics teachers. Paper presented at the International Conference on Undergraduate Physics, College Park MD.

Jackson, J., Dukerich, L., & Hestenes, D. (2008). Modeling instruction: An effective model for science education. *Science Educator*, *17*(1), 10–17.

Johnson, R. B., Onwuegbuzie, A. J., & Turner, L. A. (2007). Toward a definition of mixed methods research. *Journal of Mixed Methods Research*, *1*(2), 112–133.

Johnson-Laird, P. N. (1996). The space to think. In P. Bloom, M. A. Peterson, L. Nadel, & M. F. Garrett (Eds.), *Language and space* (pp. 437–462). Cambridge, MA: MIT Press.

Karplus, R. (1977). Science teaching and the development of reasoning. *Journal of Research in Science Teaching*, *14*, 169–175.

Krajcik, J., & Merritt, J. (2012). Engaging students in scientific practices: What does constructing and revising models look like in the science classroom? Understanding a framework for K–12 Science Education. *Science Scope*, *35*(7), 6–10.

Labov, J. (2006). National and state standards in science and their potential influence on undergraduate science education. *CBE Life Sciences Education*, *5*(3), 204–209.

Lam, S. F., Cheng, R. W. Y., & Choy, H. (2010). School support and teacher motivation to implement project-based learning. *Learning and Instruction*, *20*, 487–497.

Marx, R., & Harris, C. (2006). No child left behind and science education: Opportunities, challenges and risks. *The Elementary School Journal*, *106*(5), 467–478.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook* (2nd ed.). Thousand Oak, CA: Sage.

Miskel, C., & Ogawa, R. (1988). Handbook of research on educational administration. In N. Boyan (Ed.), *Work motivation, job satisfaction and climate* (pp. 279–304). New York: Longman.

NCLB. (2002). No Child Left Behind (NCLB) Act of 2001, Pub. L. No. 107-110, § 115, Stat. 1425.

NGSS. (2013). Next generation science standards: Adoption and implementation. Achieve, Inc. on behalf of the twenty-six states and partners that collaborated on the NGSS. Retrieved from http://www.achieve.org/files/NGSS_Workbook_PDF-3.1.13.pdf

NRC. (1996). *National science education standards. National Committee for Science Education Standards and Assessment*. Washington, DC: National Academy Press.

Passmore, C., Stewart, J., & Cartier, J. (2009). Model-based inquiry and school science: Creating connections. *School Science and Mathematics*, *109*(7), 394–402.

Passmore, C. M., & Svoboda, J. (2012). Exploring opportunities for argumentation in modeling classrooms. *International Journal of Science Education.*, *34*(10), 1535–1554.

Reiser, B. J., Berland, L. K., & Kenyon, L. (2012). Engaging students in the scientific practices of explanation and argumentation. *Science and Children*, *49*(8), 8–13.

Sanders, M. (2009). STEM, STEM education, STEMmania. *The Technology Teacher*, *68*(4), 20–26.

Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Acher, A., Fortus, D., . . . Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in science teaching*, *46*(6), 632–654.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4–14.

Streefland, L. (1985). Search for the roots of ratio: Some thoughts on the long-term learning process. *Educational Studies in Mathematics*, *16*, 75–94.

Tanner, K., & Allen, D. (2002). Approaches to cell biology teaching: A primer on standards. *Cell Biology Education*, *1*(4), 95–100.

The National Commission on Excellence in Education. (1983). *A nation at risk: The imperative for educational reform*. Washington, DC: Gardner, D. Retrieved from http://datacenter.spps.org/uploads/sotw_a_nation_at_risk_1983.pdf

Treffers, A. (1987). *Three dimensions. A model of goal and theory description in mathematics instruction. The Wiskobas Project*. Dordrecht, the Netherlands: Reidel Publishing Company.

Trygstad, P., Smith, P., Banilower, E., & Nelson, M. (2013). *The Status of Elementary Science Education: Are We Ready for the Next Generation*

Science Standards? Horizon Research, Inc. Supported by a National Science Foundation grant, DUE-0928177.

U.S. Department of Education Annual Plan. (2002–2003). Department of Education, Washington, DC. 2002-03-00, p. 149.

Van den Heuvel-Panhuzen, M. (2003). The didactical use of models in realistic mathematics education: An example from a longitudinal trajectory on percentage. *Educational Studies in Mathematics*, *54*(2/3), 9–35.

Vogler, K., & Virtue, D. (2007). "Just the facts, m'am": Teaching social studies in the era of standards and high-stakes testing. *The Social Studies*, *98*(2), 54–58.

Wilson, S. (2013). Professional development for science teachers. *Science*, *340*(6130), 310–313.

Windschitl, M., Thompson, J., & Braaten, M. (2008). Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school science investigations. *Science Education*, *92*, 941–967.

Zuzovsky, R., & Libman, Z. (2006). Standards of teaching and teaching tests: Is this the right way to go? *Studies in Educational Evaluation, 32*(1), 37–52.

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