ABSTRACT

Title of Dissertation: AN INVESTIGATION OF TEACHERS' REPORTED USE OF SCIENTIFIC PRACTICES IN ELEMENTARY INSTRUCTION: IMPLICATIONS FOR STUDENT OUTCOMES AND PRINCIPALS' SELF-EFFICACY

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Innovative and ambitious efforts are taking place to implement the new vision for science education—the Next Generation of Science Standards (NGSS) in the United States. To implement this new vision, teachers must reconsider how they use their science content knowledge (SCK) and pedagogical content knowledge (PCK) in new ways that require teachers to use the three dimensions, of the NGSS to deliver phenomena-based science instruction. The use of the science and engineering practices for students to make sense of the world will be at the core of this shift. This study was conducted in a mid-Atlantic state that is one of the leaders in the adoption and implementation of NGSS. All of the local education agencies (LEAs) are expected to implement these standards by revising their science curriculum and providing professional development to their teachers. Additionally, students in grades 5, 8, and 10 will be assessed using a new and more rigorous state science assessment based on the NGSS that will be used for school and district accountability by 2020. If students will be expected to demonstrate their knowledge of the new standards, science instruction aligned with the new standards needs to begin early. Therefore, the purpose of this study was to document the extent to which grade 1-5 teachers in one district within the state report using one of the eight NGSS science and engineering practices, specifically the development and use of models in their science instruction. Selection of this practice was supported by research that supports the development and use of models in elementary science instruction as an anchor for all the other NGSS seven science and engineering practices. This exploratory study utilized an online survey to document the frequency, barriers, and relationships and differences between teacher characteristics and demographics on the use of models to support students' learning outcomes. Findings suggest that grade 1-5 teachers have a low frequency of use of models in their science instruction. Several barriers were identified and ranked. Of significance were the inequity of resources and inadequate administrator support. Several relationships and differences were also discerned. Additionally, several implications for improvement and reform in District Q were discussed.

AN INVESTIGATION OF TEACHERS' REPORTED USE OF SCIENTIFIC PRACTICES IN ELEMENTARY INSTRUCTION: IMPLICATIONS FOR STUDENT OUTCOMES AND PRINCIPALS' SELF-EFFICACY

by

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Dedication

I dedicate my dissertation work to our Lord and Savior, my loving family, and many friends. A special feeling of gratitude goes out to my loving spouse, Carolyn Ann Rangasammy, who has been my chief anchor, offering lots of love, words of encouragement, and push of tenacity during this journey. Carolyn is also my rock for 38 wonderful loving years of marriage and counting. My sisters, whose words of wisdom, patience, and encouragement, continue to shine a bright light on me. A special dedication goes out to my eldest sister, Nalini Marray (first lady of Bishop Marray), who played a major maternal role in caring for all of my siblings and me during our early formal years when we lost our mother.

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Finally, I dedicate this dissertation to our daughter, Melissa, and son, Jermain, who have blessed us with one grandson each, Noah and Aiden, respectively. To Noah (Dude) and Aiden (Goofy 1), this dissertation is dedicated to both of you for keeping me balanced during this journey, and also to challenge both of you to go change the world and make it a better place.

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List of Abbreviations

AAAS – American Association for the Advancement of Science

CCCs – Crosscutting Concepts

CCSS – Common Core State Standards

DCIs – Disciplinary Core Ideas

ESS – Earth and Space Science

ETS – Engineering, Technology and the application of Science

IRB – Institutional Review Board

LEA – Local Education Agency

LS – Life Science

MANOVA – Multivariate Analysis of Variance

MISA – Maryland Integrated Science Assessment

MSA – Maryland Science Assessment

MSDE – Maryland State Department of Education

$(MSP)^2$ – Minority Student Pipeline, Math Science Partnership

NAEP – National Assessment of Educational Progress

NARST – National Association for Research in Science Teaching

NCES – National Center for Educational Statistics

NCTAF – National Commission on Teaching & America's Future

NGSS – Next Generation of Science Standards

NRC – National Research Council

NSES – National Science Education Standards

NSF – National Science Foundation

NSTA – National Science Teachers Association

OECD – Organization of Economic Cooperation and Development

PARCC – Partnership for Assessment of Readiness for College and Careers

PCAST – President’s Council of Advisors on Science and Technology

PCK – Pedagogical Content Knowledge

PEs – Performance Expectations

PISA – Programme for International Student Assessment

PS – Physical Science

RELA – Reading/English Language Arts

RTTT – Race To The Top

SCK – Science Content Knowledge

SEPs – Science and Engineering Practices

SIPs – Science Instructional Practices

SPSS – Statistical Package for the Social Science

SPTQ – Science Practices Teacher Questionnaire

STEM – Science, Technology, Engineering & Mathematics

Section 1: Introduction to the Problem

States and local districts across the nation are embarking on the implementation of a new approach to science instruction: The *Next Generation Science Standards* (NGSS Lead States, 2013). Grounded in research on science teaching and learning, the NGSS were released in 2013 (NGSS Lead States, 2013; NRC 2012). As of December 2016, 18 states have adopted these new standards (National Science Teachers Association, 2017).

According to Banilower et al. (2014) and supported by the National Association for Research in Science Teaching (NARST), "The Next Generation Science Standards (NGSS) have great potential to act as a catalyst for improving K–12 science education, but successful implementation of the NGSS presents a number of challenges and will require major changes throughout the education system. It will also depend on the support of other stakeholders in the system, including parents and administrators at the state, district, and school levels." (p. 1). School systems throughout the country will need to design and support long-term systemic efforts to significantly change their policies on K-12 science instruction, curriculum frameworks, instructional materials, assessment, teacher preparation, and professional development. These efforts will require extensive financial, administrative, and public support (NRC, 2012; NGSS Lead States, 2013; NSTA, 2013; Banilower et al., 2013; Bybee, 2010, 2013; Nollmeyer, 2014; Reiser, 2013; Wilson, 2013).

Preparing teachers to implement NGSS is an urgent need. The implications of the NGSS for teachers are monumental and require that all teachers deeply understand the standards and know how to motivate lessons and support students' sense-making in investigations (Schwarz, Passmore, & Reiser, 2017). Several researchers and scientific authorities such as Bybee (2013, 2014, 2015), NRC (2012), NSTA (2013), and Reiser (2013), have stated that the NGSS-intended goals can be achieved if they are implemented with fidelity in the classroom; however, this is a huge challenge for teachers in District Q. Table 1 presents the implications and instructional shifts for science teachers as they embark on this new 3-dimensional journey of teaching and learning of the NGSS.

Table 1
Educational shifts: Implications for teachers' successful implementation of NGSS.

From	**To**	**Implications**
Learning facts (e.g., parts of the cell)	Explaining natural phenomena (e.g., how cell structure relates to cell function)	Students develop models and make sense of the natural world by using evidence to develop explanations (for example, Grade 4 Life Science, Performance Expectations 1 and 2 state that students should: 1. Construct an argument that plants and animals have internal and external structures that support survival, growth, behavior, and reproduction 2. Use a model to describe that animals receive different types of information through their senses, process the information in their brain, and respond to the

From	To	Implications
		information in different ways
Single dimensions of science (e.g., disciplinary core ideas for physical science)	Interconnections of three dimensions of science (e.g., SEPs, CCCs, and DCIs)	Students use the practices to gather data and form explanations using CCCs and DCIs.
Grade-level content (e.g., middle school life science)	Progression of core ideas and practices across K-12 (e.g., coherent horizontal and vertical development of concepts and practices)	Students learn concepts below and above grade-level.
Science as a single discipline (e.g., biology)	Science and Engineering (e.g., practices of engineering design incorporated with science)	Students learn and apply the practices of engineering design.
Science as a body of knowledge (e.g., conceptual structure of a discipline)	Science as a way of knowing (e.g., nature of science as an extension of the SEPs and CCCs)	Students understand the nature of scientific knowledge.
Science as a stand-alone discipline (e.g., separate time or course in curriculum)	Science connected with common core (e.g., English language arts and mathematics incorporated with science)	Students' science education program includes experiences that incorporate reading, writing, and mathematics.

Note. Adapted from Bybee, 2014. J. Sci Teacher Education, 2014, *25*, p. 217.

Several researchers have identified three major interrelated goals on how all science teachers can effectively support student learning in the NGSS (Reiser, 2013; Passmore & Svoboda, 2012; Spillane & Callahan, 2000; Lehrer & Schauble, 2006):

1. Core Ideas: The emphasis is moved away from too much content to a focus on the in-depth development of core explanatory ideas.
2. Practices: The central role of the science and engineering practices is emphasized so that students can develop explanatory ideas and models through investigations and apply them to make sense of phenomena.

3. Coherence: Treating science learning as a coherent learning progression in which learners build ideas across time and between science disciplines.

Additionally, several studies also recommend that teachers develop pedagogical approaches to establish a culture of extensive class focus devoted to the SEPs, specifically, the use of models for the purpose of constructing explanations (Jimenenez-Aleixandre et al., 2002; Windschitl et al., 2008; Reiser, 2013; Krajcik & Merritt, 2012; Schwarz, Passmore, & Reiser, 2017; Schwarz et al., 2009).

Hence, there is a national urgency to identify the kind of professional learning opportunities that will best prepare teachers to meet the challenges of the NGSS (Haag & Megowan, 2015; NARST, 2013; Reiser, 2013). This may require a considerable investment and realignment of resources to develop the appropriate materials and tools to support both teachers and students (Wilson, 2013; Haag & Megowan, 2015).

Implications for Teaching NGSS in Elementary Grades

The NGSS will require a great deal of change in current science teaching. Teachers' science content knowledge in all four disciplinary core ideas' domains, including the Engineering, Technology, and application of Science that is interspersed throughout the NGSS, will need to be increased in order to successfully implement the NGSS (Trygstad et al., 2013; Bybee, 2013). Cooper (2013) argues that teacher preparedness is a concern at all levels, since some models of teaching (fact- and lecture-based) are incapable of satisfactorily addressing the mandates of the NGSS.

These educational shifts required by the NGSS are particularly challenging to the K-5 teachers. Past research has identified several factors that have contributed to low achievement in elementary science. These include: science as a low priority for administrators (Brogdon, 2015) and minimal or no instructional time is allocated to science instruction (Griffith, 2009; NSF, 2006; Banilower et al., 2013), elementary teachers' limited science content knowledge and pedagogical content knowledge (Foster, 2006; Hanuscin, Lee, & Akerson, 2008). In addition to concurrently addressing all three dimensions of the NGSS (as shown in Figure 2), K-5 teachers need to demonstrate and make connections to best practices, integration of the three dimensions, and the Common Core State Standards in lesson delivery (NGSS Lead States, 2013; NRC, 2012; Nollmeyer, 2014; Reiser et al., 2012; Reiser, 2013). Given the limited instructional time devoted to science in elementary grades, making these connections would help build the argument for allocating the needed instructional time to implement the NGSS as intended (Banilower et al., 2013).

Most K-5 teachers are generalists with minimal science content background (Shallcross et al., 2002; Nowicki et al., 2013). Meanwhile, the definition of a "highly qualified" elementary teacher does not take science content knowledge into account, since it only references their degree status, bachelors' or graduate level along with the necessary courses for elementary certification. Whereas, in the secondary level, science teachers are hired as "highly qualified" based on their science content courses they have taken in college and the science courses they will teach. For example, a middle school science teacher is hired as highly qualified individual to teach science in grades six through eight once he or she possesses a bachelor's or a graduate degree in one of several science majors along with the necessary certification courses. One implication for the successful implementation of the NGSS, where the philosophy is, "all standards all students" is that teacher certification should change to "all domains, all teachers."

A key aspect of the NGSS is the development and use of models in science instruction. Several researchers argue that basic competencies to teach the NGSS should now include use of models, using evidence as the basis for explanations and arguments (Bybee, 2014; Zangori, Forbes, & Biggers, 2013). In terms of the foundational concept of *"sense-making"* defined as the conceptual process in which a learner actively engages with the natural or designed world; wonders about it; and develops, tests, and refines ideas with peers and the teacher (Schwarz, Passmore, & Reiser, 2017), several studies have shown that elementary science teachers underemphasize science sense-making in their lessons (Forbes, Biggers, & Zangori, 2013; Forbes & Davis, 2010; Zangori, Forbes, & Biggers, 2013). This lack of emphasis on sense-making will pose a major learning problem for elementary students if teachers do not shift their practice to successfully engage their students in the use of the sense-making SEPs of the NGSS, specifically, the use of models for the purpose of constructing explanations (Hakuta, Santos, & Fang, 2013; Cavagnetto, Hand, & Norton-Meier, 2010; Hapgood, Magnusson, & Palincsar, 2004; Hardy, Jonen, Moller, & Stern, 2006; McNeill, 2011; Metz, 2011; Samarapungavan, Mantzicopoulos, & Patrick, 2008; Songer & Gotwals, 2012; Schwarz, Passmore, & Reiser, 2017; Schwarz et al., 2009; Windschitl & Thompson, 2013).

Challenges in the District of Study

This study was conducted in a large urban/suburban district in a mid-Atlantic state. For purposes of the study, the district is referred to as District Q. Bybee (2014) has noted the ways in which the reforms of the NGSS will influence the educational system and classroom teaching, student learning, and achievement. District Q faces some particular challenges given its demographics and history of low science achievement on the current science assessment. District Q is a highly diverse district with a K-12 enrollment of over 130,000 students, comprising of 58% African Americans, 31% Hispanic, 4% White, 3% Asian, and 4% two or more mixed races. Of its 68,000 elementary students, 67% are FARMS, 23% LEP, 11% Special Education and 46% are housed in Title I schools. For the past five years, the proportion of District Q's 5th grade students scoring at or above proficient on the 5th grade state science assessment has remained relatively flat with an average of 54.8% compared to the state's average proficiency of 65.9%.

According to Table 2, District Q lags the state by 11.1% and ranks 22nd out of the 24 Local Education Agencies (LEAs) in the state with respect to the proportion of students reaching proficiency on the State's 5th grade Science Assessment (Maryland Report Card, 2015). During this period, District Q has had three turnovers in superintendents, severe budgetary cuts and staff reduction, and an increased percentage of LEP elementary students from 18% in 2011 to 21% in 2015 (Mdreport Card, 2017). Student success in the 5th grade matters when one looks at the larger picture of K-12 Science Education as it sets the stage for motivating students to succeed in more challenging science curricula in upper grades (Gallenstein, 2005; Mantzicopoulos, Patrick, & Samarapungavan, 2008).

Table 2

FY11-15 State (LEAs) 5th Grade Science Assessment % Proficiency Scores

LEAs	**FY11**	**FY12**	**FY13**	**FY14**	**FY15**
State's Average	66.8	68.5	67.0	64.2	63.3
District A	75.5	82.4	74.3	78.2	73.0
District B	75.8	77.4	77.0	76.4	73.7
District C	36.1	38.6	36.3	30.8	28.3
District D	65.1	67.7	66.6	64.5	61.0
District E	84.9	86.5	85.2	81.6	81.3
District F	82.1	82.5	75.5	70.4	75.4
District G	80.9	82.2	80.5	80.2	78.3
District H	60.5	61.9	59.7	57.0	58.3
District I	62.9	63.0	64.4	59.7	64.4
District J	65.4	61.6	60.7	50.0	45.2
District K	80.0	82.4	76.9	76.8	76.6
District L	77.2	75.8	74.9	73.3	67.2
District M	77.2	76.8	76.5	74.1	71.1
District N	76.7	78.3	79.1	76.0	76.2
District O	74.2	69.1	71.5	71.6	66.2
District P	72.3	73.0	72.4	68.2	70.1
District Q	**55.1**	**58.0**	**55.3**	**52.6**	**53.0**
District R	82.5	86.5	78.4	72.8	79.9
District S	79.3	77.9	72.4	73.9	56.8
District T	76.7	80.0	74.5	73.4	71.9
District U	76.2	78.1	72.4	70.6	66.4
District V	74.0	72.2	70.0	63.8	65.7
District W	56.7	58.9	59.4	57.1	54.2
District X	66.9	77.8	72.5	70.0	65.8

Note. *Data from http://reportcard.msde.maryland.gov*

Fiscal Year 16 was the final year of administration for the 5th and 8th grade State Science Assessment (MSDE, 2016). Since the state adopted the Next Generation of Science Standards (NGSS) in June 2013, a new integrated NGSS-aligned state assessment has been developed and is being piloted. It will be fully implemented in FY20 (MSDE, 2013).

The Influence of the NGSS on Instruction in District Q

Figure 1 below captures the influences of the NGSS on science instruction.

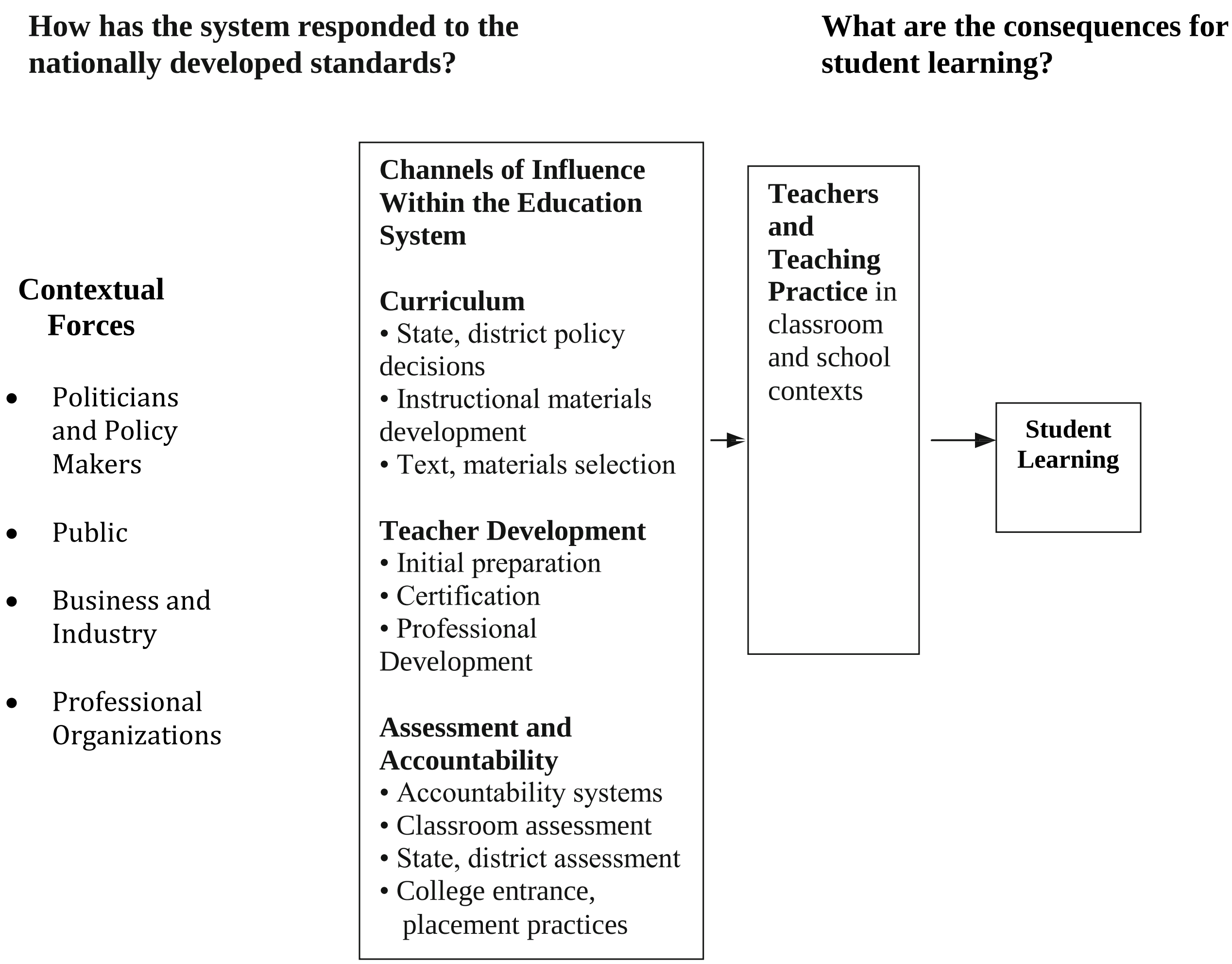


Figure 1. Influence of Standards on the Educational System**.** A Conceptual Map for Investigating the Influence of Nationally Developed Standards for Mathematics, Science, and Technology Education, adapted from NRC, 2002, p. 53; Bybee, 2014, p. 214.

Figure 1 above captures the influences of the NGSS on science instruction.

It is apparent that teachers in District Q need to shift their instruction and need to know and feel confident about how to support students' engagement through the practices of the NGSS, specifically modeling.

Understanding the Educational Shifts in the NGSS

Bybee (2014) asserts that the NGSS offers an opportunity to support and improve curriculum, teacher development, assessment and accountability, and ultimately student achievement. In order to bring this opportunity to reality, Bybee further argues that science teachers must address the educational shifts in NGSS, since they have direct implications for teacher development. Some may ask, "why new science standards?" (National Science Board, 2012, 2014, 2016; NRC, 2012). According to several researchers and Science, Technology, Engineering and Mathematics (STEM) organizations, including the National Research Council (2012), National Science Teachers Association (2013), and President's Council of Advisors on Science and Technology (PCAST, 2010), there are several compelling reasons. Science standards were not revised for the last 17 years. Second, since that time, many advances have occurred in the fields of science and science education, as well as in the innovation driven economy (NRC, 2014). According to NRC, the United States has a porous and weak K-12 STEM talent pipeline, with too few students entering STEM majors and careers at every level—from those with relevant postsecondary certificates to doctoral degrees; hence, new science standards are needed to stimulate and build interest in STEM (NGSS Lead States, 2013).

The urgency to address science teaching is compounded by the lack of increased student achievement on international assessments. According to the National Center for Education Statistics (NCES, 2011), science and mathematics achievement in the United States continues to lag compared to other countries. The United States ranked 20th in science and 27th in mathematics on the 2012 Programme for International Student

Assessment (PISA). Just over one-quarter (26%) of 15-year-olds in the United States do not reach the PISA baseline Level 2 of mathematics proficiency (Organization for Economic Co-operation and Development, OECD, 2012). In addition, more than a third of U.S. eighth-graders scored below basic on the 2011 National Assessment of Educational Progress (NAEP) science assessment (NCES, 2011).

This lag in student achievement in science in the United States is viewed as impacting our global competitiveness. However, some researchers argue that PISA has inherent flaws and should not be used to indict or commend educational systems in the United States (OECD, 2013; Tienken, 2014). Given the fact that there is a strong relationship between poverty and test scores (OECD, 2013) and the United States has one of the highest poverty rates in major industrialized countries (OECD, 2009), poverty can explain up to 46% of the PISA mathematics score in OECD countries, to include the United States (OECD, 2013; Tienken, 2014). Additional flaws include selection bias, lack of cultural relevance, lack of support to diverse student populations as in the United States (Tienken, 2014).

In 2009, a Carnegie Corporation of New York/Institute for Advanced Study commission of researchers and public and private leaders concluded that:

> the nation's capacity to innovate for economic growth and the ability of American workers to thrive in the modern workforce depend on a broad foundation of math and science learning, as do our hopes for preserving a vibrant democracy and the promise of social mobility that lie at the heart of the American dream. (p. v11)

According to NGSS Lead States (2013):

> We cannot successfully prepare students for college, careers, and citizenship unless we set the right expectations and goals. While standards alone are no silver bullet, they do provide the necessary foundation for local decisions around curriculum, assessments, and instruction. Implementing improved K-12 science standards will better prepare high school graduates for the rigors of college and careers. In turn, employers will be able to hire workers with strong science-based skills—including specific content areas but also skills such as critical thinking and inquiry-based problem solving (p. xv).

The overarching goal of the NGSS is to ensure that all 12th grade students have some appreciation of the beauty and wonder of science; possess sufficient knowledge of science and engineering to engage in public discussions on related issues; are careful consumers of scientific and technological information related to everyday lives; are able to continue to learn about science outside school; and have the skills to enter careers of their choice, including in science, engineering, and technology (NRC, 2012). According to the NRC, K-12 science education in the United States fails to achieve these outcomes and the NRC identified several factors. These include lack of a K-12 learning progression in science, emphasis on discrete facts and a focus on breadth over depth, and minimal engaging opportunities for students to experience how science is done (NRC, 2012; NGSS Lead States, 2013; NSTA, 2013; Bybee, 2010, 2013, 2014; Nollmeyer, 2014). The NGSS K-12 framework is designed to address and overcome this deficiency of the current state of science education in the United States.

The NGSS had two public reviews with extensive feedback from anyone who wished to provide it. The final version was published in 2013. In all, 26 states initially signed on in support of the development of the NGSS. It was based on the highly researched conceptual *Framework for K-12 Science Education* developed by the National Research Council (2012). For purposes of clarity, the difference between the NGSS and the *Framework for K-12 Science Education* is discussed in the next section.

Conceptual Shifts: Demands on Teacher Practice

Seven conceptual shifts are described in Appendix A *of* NGSS (Appendices, NGSS Lead States, 2013; Reiser, 2013; NSTA's Position Statement on NGSS, 2013).

Shift 1: K-12 science education should reflect the interconnected nature of science as it is practiced and experienced in the real world. This shift recommends that students be engaged in concurrently doing science through the three dimensions; the eight Science and Engineering Practices, seven Crosscutting Concepts, and the Disciplinary Core Ideas as opposed to status quo where most state and districts, including our district, address these dimensions separately. Hence, this shift demands that teacher practice in the district shift to one that provides deeper integration of experiences and understanding of science concepts and practices. From a district perspective, this new vision of implementation of the NGSS will impact all stakeholders and instruction, curriculum, assessment, teacher preparation, and professional development.

Shift 2: The NGSS are student performance expectations, not curriculum. Even though within each performance expectation, Science and Engineering Practices (SEPs) are partnered with a particular Disciplinary Core Idea (DCI) and Crosscutting Concept (CCC) in the NGSS, these intersections do not predetermine how the three are linked in curriculum, units, or lessons. The demand here is that District Q's grade 1-5 teachers will have to experience this model in professional learning opportunities sessions in order to address the demands of this shift. Performance expectations simply clarify the expectations of what students will know and be able to do by the end of the grade or grade band.

Shift 3: The Science concepts in the NGSS are built coherently from K-12. The focus is on a few Disciplinary Core Ideas (DCIs) as a key aspect of a K-12 learning progression. The progression of knowledge occurs from grade band to grade band that gives students the opportunity to learn more complex material, leading to an overall understanding of science by the end of high school.

The NGSS provides a more coherent progression aimed at overall scientific literacy with instruction focused on a smaller set of ideas and an eye on what the student should have already learned and what they will learn at the next level. Second, the progressions in the NGSS automatically assume that the student has learned the previous material. Choosing to omit content at any grade level or band will impact the success of the student in understanding the core ideas and put additional responsibilities on teachers later in the process (NRC, 2012). This shift is best summarized by *the K-12 Framework for Science Education* which states,

"To develop a thorough understanding of scientific explanations of the world, students need sustained opportunities to work with and develop the underlying ideas and to appreciate those ideas' interconnections over a period of years rather than weeks or months" (p. 10).

Shift 4: The NGSS focus on deeper understanding of content as well as application of content. The *NGSS* identified a smaller more teachable set of Disciplinary Core Ideas that students should know by the time they graduate from high school. The shift for teachers is that they need to focus on the core ideas—not necessarily the facts that are associated with them, but making sense of phenomenon. Reiser (2013) argues that "extensive class focus needs to be devoted to argumentation and reaching consensus about ideas, rather than having textbooks and teachers present ideas to students." The *Framework for K-12 Science Education* states:

> The core ideas also can provide an organizational structure for the acquisition of new knowledge. Understanding the core ideas and engaging in the scientific and engineering practices helps to prepare students for broader understanding, and deeper levels of scientific and engineering investigation, later on—in high school, college, and beyond. (p. 25)

Shift 5: Science and Engineering are integrated in the NGSS, from K-12. The idea of integrating technology and engineering into science standards is not new. Chapters on the nature of technology and the human-built world were included in Science for All Americans (AAAS, 1990, 1993). Standards for "Science and Technology" were included for all grade spans in the National Science Education Standards (NRC, 1996). Despite these early efforts, however, they have failed to receive the attention they deserve (NGSS Lead States, 2013; NSTA, 2013). A significant difference in the NGSS is the integration of engineering and technology into the structure of science education. This integration is achieved by raising engineering design to the same level as scientific inquiry in classroom instruction when teaching science disciplines at all levels and by giving core ideas of engineering and technology the same status as those in other major science disciplines (NRC, 2012).

The rationale for this increased emphasis on engineering and technology is both aspirational and practical (NRC, 2012). From an aspirational standpoint, the science and engineering are needed to address major world grand challenges for engineering such as generating sufficient clean energy, preventing and treating diseases, maintaining supplies of food and clean water, and solving the problems of global environmental change (National Academy of Engineering, 2008). The NGSS Lead States assume that these important challenges will motivate many students to continue or initiate their study of science and engineering. From a practical standpoint, the engineering and technology provide opportunities for students to deepen their understanding of science by applying their developing scientific knowledge to the solution of practical problems. Both positions converge on the powerful idea that by integrating technology and engineering into the science curriculum, teachers can empower their students to use what they learn in their everyday lives (NRC, 2012). Several researchers argue that all science teaching and learning should involve engaging in the SEPs in order to help students make sense of their world (Schwarz, Passmore, & Reiser, 2017; Reiser, 2013; Passmore & Svoboda, 2012; Windschitl, Thompson, & Braaten, 2008; Forbes, Biggers, & Zangori, 2013). NGSS Lead States, Appendix C, also cited several researchers that support the notion that student engagement in practices helps reduce achievement gaps (Barton et al., 2008; Brotman & Moore, 2008; Enfield et al., 2008; Lee et al., 2005; Page, 2007).

Shift 6: The NGSS is designed to prepare students for college, career, and citizenship. Appendix A of the NGSS states that "all students no matter what their future education and career path, must have a solid K-12 science education in order to be prepared for college, careers and citizenship." In a complex technological and global society, science and science education are central to the lives of all Americans where science knowledge is critical to sense making. Science is also at the heart of the United States' ability to continue to innovate, lead, and create the jobs of the future. The demands and rigorous content of NGSS can provide a solid foundation for students entering a variety of STEM fields, thereby, reducing the STEM professional gap in the United States (Bybee, 2014; NSTA, 2013).

Shift 7: The NGSS and Common Core State Standards (English Language Arts and Mathematics) are aligned to facilitate integrated teaching and learning. The timing of the release of NGSS comes as most states, including Maryland, are implementing the Common Core State Standards (CCSS) in English Language Arts and Mathematics. This is important to science for a variety of reasons. First, there is an opportunity for science to be part of a child's comprehensive education. The NGSS are aligned with the CCSS to ensure a symbiotic pace of learning in all content areas. The three sets of standards overlap in meaningful and substantive ways and offer an opportunity to give all students equitable access to learning standards through collaborative opportunities of language and literacy regarding the complementarity of CCSS and NGSS (Cheuk, 2012). Future science assessments will not assess students' understanding of core ideas separately from their abilities to use the practices of science and engineering. Students will be assessed on all three dimensions (SEPs, DCIs, and CCCs) of the NGSS together, showing that they not only "know" science concepts, but also, can use their understanding to investigate the natural world through the practices of science inquiry, or solve meaningful problems through the practices of engineering design (NRC, 2012).

2012 *Framework for K-12 Science Education*. The 2012 *Framework for K-12 Science Education* was the first step in a process to create standards in K-12 Science Education (NRC, 2012). The Carnegie Corporation of New York, in collaboration with the Institute for Advanced Studies, established a commission that issued the *Opportunity Equation* demanding a common set of high quality K-12 science standards.

The vision and goal for the K-12 framework is based on NRC's claim (2012):

> Science, engineering, and technology permeate nearly every facet of modern life, and they also hold the key to meeting many of humanity's most pressing current and future challenges. Yet, too few United States workers have strong backgrounds in these fields, and many lack even fundamental knowledge of them. This national trend has created a widespread call for a new approach to K-12 science education in the United States. (p. 1)

The Carnegie Corporation led this project through funding a two-step process: (a) the development of the 2012 NRC's *Framework for K-12 Science Education,* and (b) the development of a separate document – the next generation of science standards grounded in NRC's framework and led by Achieve, Inc. (NGSS Lead States, 2013).

The 2012 framework builds on the existing strong foundations of previous studies that identified and described major ideas for K-12 science education. These include *Science for All Americans and Benchmarks for Science Literacy* (1993), developed by the American Association for the Advancement of Science (AAAS), and the *National Science Education Standards* (1996), developed by NRC. More recent collaborations also informed the framework; these include the AAAS Project 2061 and the National Science Teachers Association (NRC, 2012). The framework is based on current research on teaching and learning in science in combination with two decades of efforts to define foundational knowledge and skills for K-12 science and engineering (NRC). It recommends that K-12 science education be built around three major dimensions: Science and Engineering Practices (SEPs), Crosscutting Concepts (CCCs), and Disciplinary Core Ideas (DCIs) in four disciplinary areas: physical sciences; life sciences; earth and space sciences; and engineering, technology, and applications of science. The framework focuses on a limited number of DCIs and CCCs, so that students are constantly building on and revising their knowledge and abilities over multiple years, and concurrently supporting the integration of the SEPs and engineering process throughout their K-12 science experience (NRC, 2013). The NGSS Lead States (2013) recommend that all three dimensions be integrated into standards, curriculum, instruction, and assessment. The SEPs play a central role in defining all NGSS standards (Reiser, 2013). This is a major shift for science teaching and learning. The SEPs are designed to allow students to figure out phenomenon through posing questions, designing investigations, building explanations and models of findings, and engaging in argumentation through social interaction and discourse to reach consensus (Reiser, 2013). Prior standards such as the National Science Education Standards (NRC, 1996) and the American Association for the Advancement of Science’s Benchmarks (AAAS, 1993) separated the content standards and inquiry standards (process skills).

The K-12 framework integrates content and practices to reflect the nature of science and engineering in the natural and designed world. The term “inquiry” has evolved into practices that allow for disciplinary approaches to argumentation that explicitly guide knowledge building in principled ways so that the work of building, testing, and refining knowledge is realized through scientific discourse and work with scientific representation and tools (Reiser, 2013).

Elements of the NGSS

The NGSS share the same vision, three dimensions, and overarching goals as the Framework for K-12 Science Education (see Figure 2). The NGSS expand the Framework for K-12 Science Education. As mentioned earlier, the development of the NGSS was a two-step process. The first step was the development of the Framework for K-12 Science Education. This was a critical first step, since it was grounded in the most current research on science teaching and learning and identified the science all kindergarten through twelve (K-12) students should know (NRC, 2012). The second step was the development of the NGSS, which represent a set of K-12 science standards, rich in content and practice, and arranged in a coherent manner across disciplines and grades to provide all students an internationally-bench marked college- and career-ready science education (NGSS Lead States, 2013).

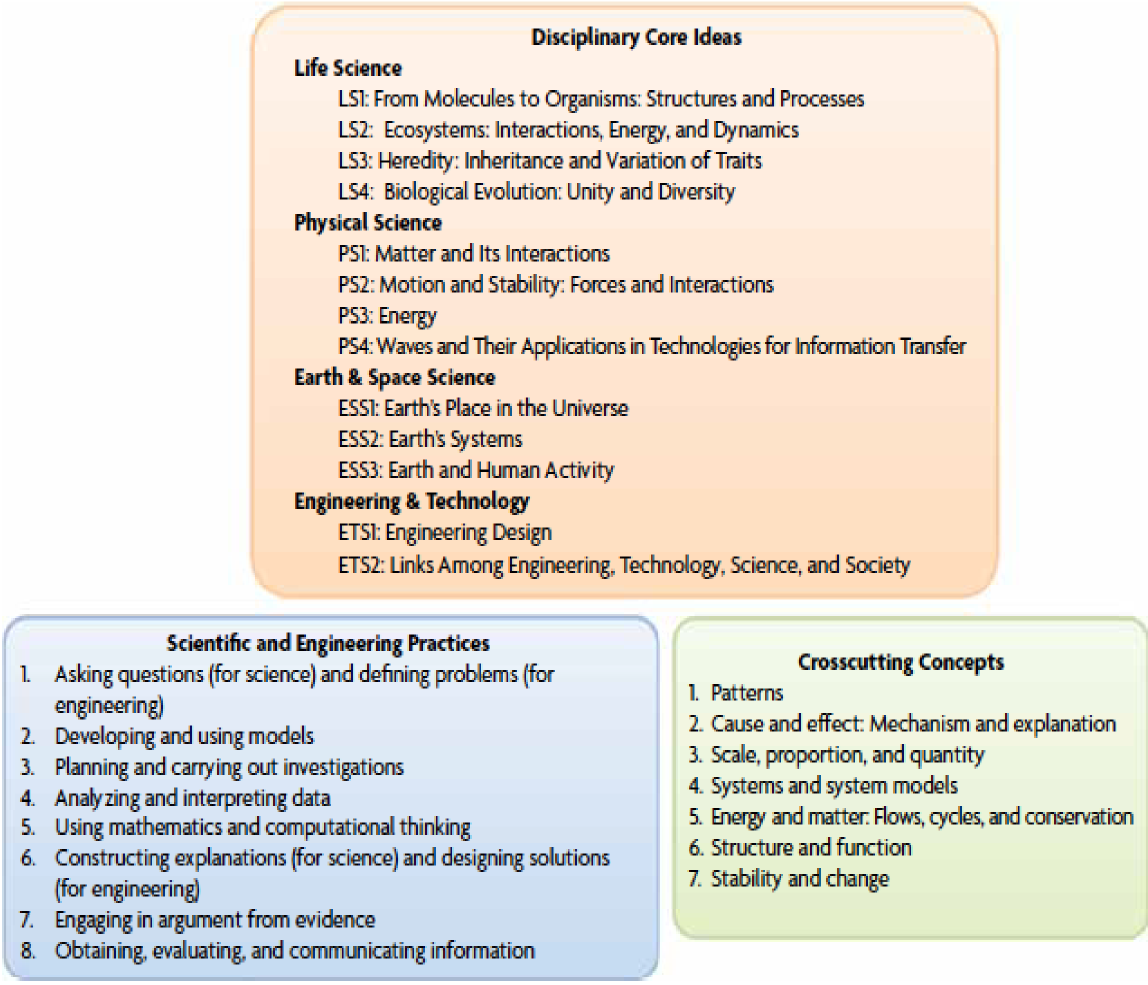


Figure 2. Summary of the Three Dimensions of Next Generation of Science Standards. Adapted from Duncan & Cavera, DCIs, SEPS & CCC, Oh My! Science Teacher, October 2015, p. 68.

In this section, the differences between past science standards and NGSS are discussed. The NGSS are distinct from prior science standards such as *Science for All Americans and Benchmarks for Science Literacy* (AAAS, 1993), and the *National Science Education Standards* (NRC, 1996), in three distinct ways: Performance, Foundation, and Coherence (NGSS Lead States, 2013). Unlike these prior science standards that assessed students on what they should "know" or "understand," NGSS developed *performance expectation (PEs)* that state what students should be able to do in order to demonstrate that they have met a standard, thus providing the same clear and specific targets for curriculum, instruction, and assessment (NGSS Lead States, 2013). An example of a fifth grade Physical Science, Performance Expectation is described in Figure 3 below.

Students who demonstrate understanding can: **5-PS1-1. Develop a model to describe that matter is made of particles too small to be seen.** [Clarification Statement: Examples of evidence supporting a model could include adding air to expand a basketball, compressing air in a syringe, dissolving sugar in water, and evaporating salt water.] [*Assessment Boundary: Assessment does not include the atomic-scale mechanism of evaporation and condensation or defining the unseen particles.*]		
The performance expectation above was developed using the following elements from the NRC document *A Framework for K-12 Science Education*:		
Science and Engineering Practices Developing and Using Models Modeling in 3–5 builds on K–2 experiences and progresses to building and revising simple models and using models to represent events and design solutions. Use models to describe phenomena.	Disciplinary Core Ideas PS1.A: Structure and Properties of Matter Matter of any type can be subdivided into particles that are too small to see, but even then the matter still exists and can be detected by other means. A model showing that gases are made from matter particles that are too small to see and are moving freely around in space can explain many observations, including the inflation and shape of a balloon and the effects of air on larger particles or objects.	Crosscutting Concepts Scale, Proportion, and Quantity Natural objects exist from the very small to the immensely large.
Connections to other DCIs in fifth grade: N/A		
Articulation of DCIs across grade levels: **2.PS1.A**; **MS.PS1.A**		
Common Core State Standards Connections: *ELA/Literacy -*		

RI.5.7	Draw on information from multiple print or digital sources, demonstrating the ability to locate an answer to a question quickly or to solve a problem efficiently. *(5-PS1-1)*
Mathematics -	
MP.2	Reason abstractly and quantitatively. *(5-PS1-1)*
MP.4	Model with mathematics. *(5-PS1-1)*
5.NBT.A.1	Explain patterns in the number of zeros of the product when multiplying a number by powers of 10, and explain patterns in the placement of the decimal point when a decimal is multiplied or divided by a power of 10. Use whole-number exponents to denote powers of 10. *(5-PS1-1)*
5.NF.B.7	Apply and extend previous understandings of division to divide unit fractions by whole numbers and whole numbers by unit fractions. *(5-PS1-1)*
5.MD.C.3	Recognize volume as an attribute of solid figures and understand concepts of volume measurement. *(5-PS1-1)*
5.MD.C.4	Measure volumes by counting unit cubes, using cubic cm, cubic in, cubic ft, and improvised units. *(5-PS1-1)*

Figure 3. Example of a 5th Grade Performance Expectation. Adapted from NGSS Lead States. Retrieved from http://www.nextgenscience.org/pe/5-ps1-1-matter-and-its-interactions

As can be seen from Figure 3, each performance expectation incorporates all three dimensions – a science or engineering practice, a core disciplinary idea, and a crosscutting concept. The development and use of models is the core of several grade 1-5 PEs (NGSS Lead States, 2013). Additionally, each set of performance expectations lists connections to other ideas within disciplines of science and engineering, and with Common Core State Standards in Mathematics and English Language Arts (NGSS Lead States, 2013). Figure 4 demonstrates the interconnections and commonalities of the practices in Science, Mathematics, and English Language Arts.

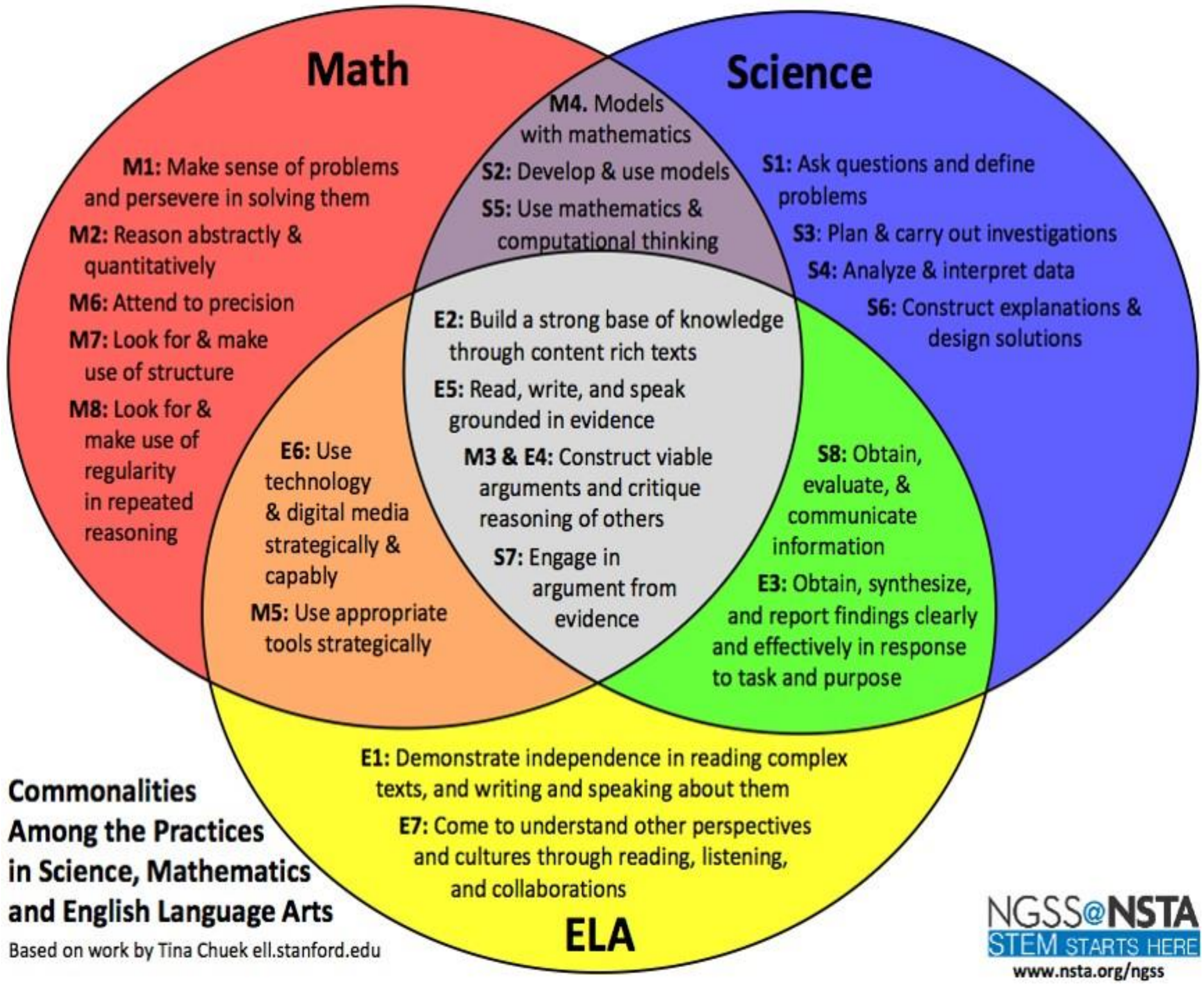


Figure 4. Relations and convergences in literacy, math and science, and engineering practices. Adapted from Cheuk, 2012, and NGSS@NSTA.

Of significance, the DCIs can be viewed as the science content to be taught. Past science standards, such as the National Science Education Standards (NRC, 1996), prior to the *K-12 Framework for Science Education* and the *NGSS* which, AAAS (1990) referred to as, “overstuffed and undernourished” (p. viii) are reduced to core ideas that every student should know upon graduation from high school (NGSS Lead States, 2013). These past standards, which NSF (1996) referred to as a, “milewide and inch-deep" (p. 1) are now concentrated into four domains as described in Figure 2: (a) Life Science (LS), (b) Physical Science (PS), (c) Earth and Space Science (ESS), and (d) Engineering, Technology, and applications of Science (ETS).

As mentioned earlier, currently, most state and district standards express these three dimensions (SEPs, DCIs, and CCCs) of the NGSS as separate entities, leading to their separation in both instruction and assessment (NGSS Lead States, 2013). The 5^{th} grade state assessment is based on six standards (skills and processes, earth and space science, life science, chemistry, physics and environmental science) that were assessed separately. For example, in the 5^{th} grade process skills standards, such as *make use of and analyze models, use of tables and graphs to summarize and interpret data*, and content standards, such as a chemistry standard, *provide evidence from investigations to identify the processes that can be used to change materials from one state of matter to another*, are assessed separately (MSDE, 2016). Whereas, the NGSS Performance Expectations focus on demonstrating understanding and application as opposed to memorization of facts devoid of context (NGSS Lead States, 2013; NRC, 2012). The new 5^{th} and 8^{th} grade State Science Assessments will be designed with all three dimensions, so that the SEPs and CCCs are at the core of the assessment items when addressing content in the DCIs' four domains (MSDE, 2016).

Science and Engineering Practices (SEPS)

In this section, the role of the SEPs and sense-making in supporting teacher practice is further discussed. The need for teachers to use and develop models for the purpose of constructing explanations is also discussed.

Sense-making and teacher practice. The lack of science content knowledge and pedagogical content knowledge makes it difficult for teachers to ask or answer science questions (Smith & Neale, 1989; Roychoudhury & Kahle, 1999). K-12 teachers will need to shift their teaching delivery systems to integrate all three dimensions in the NGSS through lessons that are grounded in phenomena and sense-making of the natural and designed world (Reiser, Berland, & Kenyon, 2012; Duschl, Schweingruber, & Shouse, 2007; Schwarz, Passmore, & Reiser, 2017).

The term *sense-making* has its origins from the disciplines of communication, information systems, and knowledge management (Dervin, 1998). Sense-making according to Dervin (1998), is defined as a verb since 1972, where she defined knowledge and information as "a product of and fodder for sense making and unmaking." The overview of sense-making research website (Dervin, 1983) indicates that sense-making was influenced by a variety of theorists in the fields of philosophy, sociology, psychology, education, cultural studies, communication and feminist cultural and postmodern studies (Dervin, 1983, 1998). These include the constructivist learning theories of John Dewey and Jerome Bruner. Over the decades, sense-making has evolved to human-computer interactions and organizational management systems (Weick, Sutcliffe, & Obstfeld, 2005). Sense-making is seen by several researchers as a way of making meanings materialize through gap-bridging, social interactions, language, talk and communication where situations, organizations, and environments are talked into existence (Dervin, 1998; Weick, Sutcliffe, & Obstfeld, 2005; Klein, Moon, & Hoffman, 2006). Additionally, sense-making is viewed as a psychological phenomenon where creativity, curiosity, comprehension, mental modeling situation awareness and gap-bridging, can collectively serve to develop expert decision making and explain the meanings of the observable diverse and complex world (Klein, Moon, & Hoffman, 2006). Hence, in today's context, sense-making can be seen as a methodology or process by which people give meaning to experiences or how people make sense out of their experience in the world (Wikipedia, 2017; Klein, Moon, & Hoffman, 2006). In this context, sense-making can be seen as a proactive process of trying to figure out the way the world works for scientific questions and exploring how to create models for the purpose of constructing explanations (Schwarz, Passmore, & Reiser, 2017).

Models and connections to the other SEPs. According to the NRC (2012), "Scientists construct mental and conceptual models of phenomenon. Mental models are internal, incomplete, unstable, and functional. They serve the purpose of being a tool for thinking with, making predictions and making sense of experience. Conceptual models are explicit representations and in most cases analogous to the phenomenon they represent. Conceptual models include diagrams, physical replicas, mathematical representations, analogies and computer simulations" (p. 56). For purposes of this research, the term "models" refers to conceptual models. Modeling can begin in the earliest grades, with students' models progressing from concrete "pictures' and/ or physical scale models (e.g., a toy car) to more abstract representations of relevant relationships in later grades, such as a diagram representing forces on a particular object in a system in order to develop explanations of what occurred during their investigations (NRC, 2012). Several researchers further assert that sophisticated types of models should increasingly be used across grades, both in instruction and curriculum materials. The quality of student-developed models will highly be dependent on prior knowledge and skill. Curricula will explicitly need to stress the role of models and provide teachers and students with modeling resources such as Concord Consortium and PhET Simulations (NRC, 2012; Baek & Schwarz, 2015; The Concord Consortium, 2017; PhET Interactive Simulations, 2017).

As discussed earlier, there are eight SEPs which are central to the successful implementation of the NGSS, specifically modeling and model development which is viewed as an anchor practice that motivates, guides, and informs the other seven SEPs and brings them into a broader approach to productive sense-making (Schwarz, Passmore, & Reiser, 2017). Figure 5 demonstrates the anchoring interconnectedness of developing and using models to explain phenomena with respect to the other seven SEPs.

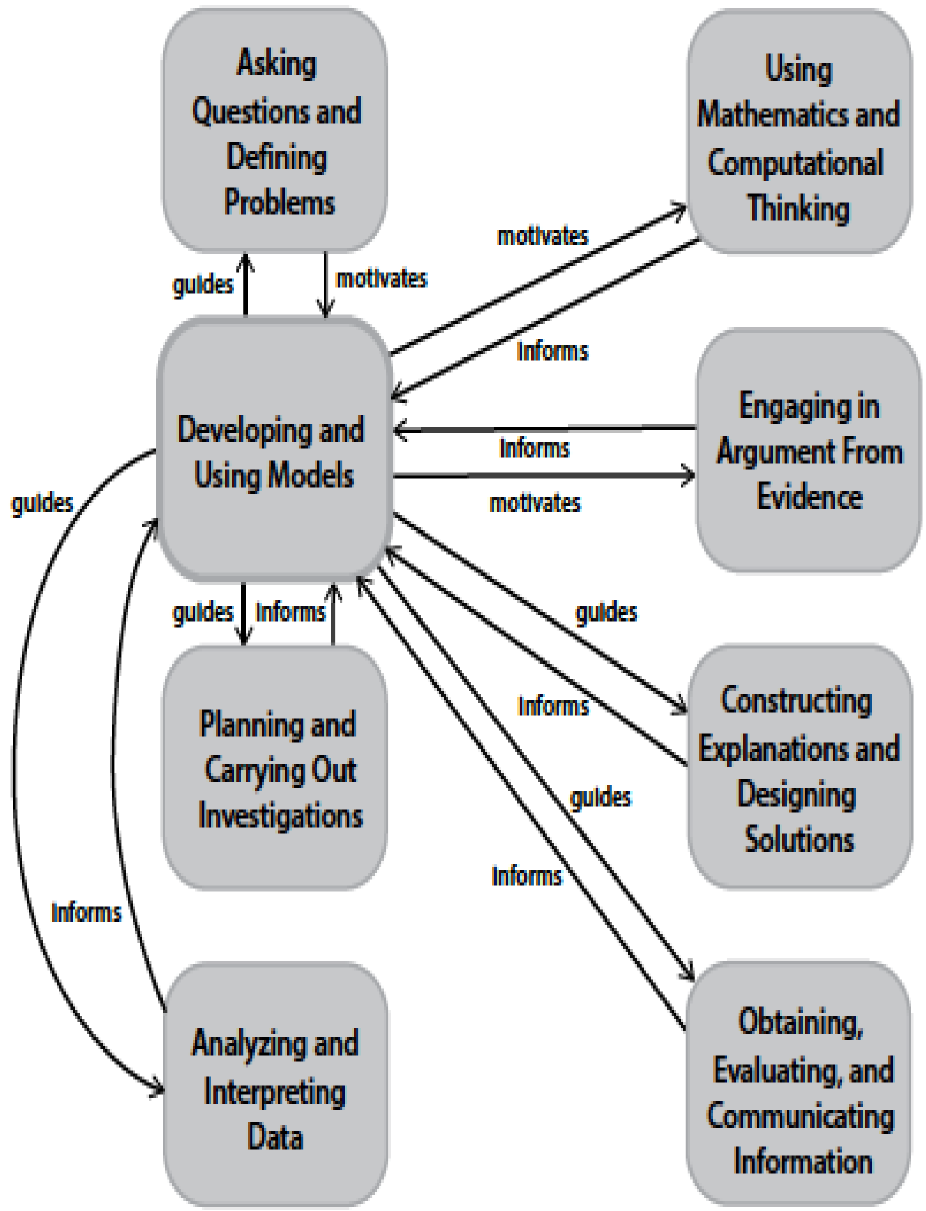


Figure 5. Models as an Anchor Practice. Adapted from Schwarz, Passmore & Reiser, p.120 (2017). *Helping Students Make Sense Of The World Using Next Generation Science And Engineering Practices.*

From Figure 5, models can be seen as the anchor SEP that can guide the use of all other SEPs. For example, models can elicit the identification of questions and prediction of answers, empirical investigations, assist in the analysis and interpretation of data, and can be revised to answer, explain, predict, solve problems, elicit the development of explanations and argumentation, and guide the organization of relevant information in order to communicate ideas of the natural and designed world. This is consistent with the first implication for NGSS implementation (see Table 1), where the importance of models as a tool for thinking in science has implications for implementation. Teachers are expected to create a classroom culture where students are developing models to make sense of the natural world by using evidence to develop explanations. Moreover, scientific modeling (practice 2 of the SEPs) can be powerful tools that help students at all age levels make sense of natural earth systems such as the water cycle. Using these classroom approaches will help elementary students begin developing the ability to use models scientifically, which in turn will create a strong foundation for science literacy (Forbes, Vo, Zangori, & Schwartz, 2015). Few studies have explored this essential practice among elementary teachers (Zangori et al., 2013). The construction and use of models in the development of scientific explanations is a critical skill that elementary students should master in order to build a strong foundation for how scientists investigate and make sense of natural phenomena. Everyday use of this practice is seen as a way to support and increase students' proficiency on local, state, and federal assessments such as new NGSS aligned State Science Assessment and the Partnership for Assessment of Readiness for College and Careers (PARCC).

Current Initiatives to Address Teacher's Capacity NGSS in the State

For the past several years, numerous state and local initiatives have been implemented to address science teachers' capacity in the district. For purposes of this research, initiatives that are directly related to increasing teachers' science content knowledge (SCK) and pedagogical content knowledge (PCK) are summarized in Appendix A. Examples include the State's University System of Minority Student Pipeline (MSP) [2] Math Science Partnership, the state's STEM Grants, Race to The Top (RTTT) STEM Grant, District Q's Literacy Initiative and K-12 NGSS implementation and current University partnerships in building teachers and administrators' STEM content and pedagogical capacity.

In partnership with several local universities and District Q, the State's University System received $12.4 million, for the period 2008-2013, from the National Science Foundation to support P-20 STEM education through several strategies on improving the district's K-12 science teachers' capacity in elementary, middle, and high schools to effectively teach science to underrepresented minority. Of significance to this study is Strand I of the MSP grant; over 750 teachers of grades 4-8 experienced professional development sessions around the principles of teaching and learning science through inquiry. Schools with participating teachers demonstrated significant gains on the Maryland Science Assessment (MSA) compared to their non-participating peers (National Science Foundation, 2008).

In 2010-2015, several state and local initiatives that supported science teachers' capacity were funded with the state's RTTT Grant (MSDE, 2010). These include the development of State's STEM standards, approval of elementary teachers' STEM Certification Program, Summer Educator Effectiveness Academies, and College and Career Readiness Conferences. District Q received a RTTT STEM Grant that focused on secondary teachers' STEM capacity (MSDE, 2010; District Q Grants Office, 2010). Additionally, the district received the State STEM grant in FY12 and FY13 (MSDE, 2013). These STEM grants were used to increase elementary teachers' capacity through the curricular infusion and implementation of selected *Engineering is Elementary* modules (eie.org, 2013; District Q Grants Office, 2012, 2013).

Citing that District Q is the second from the bottom of all the 24 LEAs in the state in student achievement, the district implemented a system wide literacy initiative in FY16 in support of increased student achievement through the building of our K-12 teachers' increased capacity on literacy connections to content in teaching and learning (District Q, Literacy Plan, 2015). Concurrently, in support of student achievement through collaborations with internal district offices such as the Office of Talent Development, the Science Office, MSDE, and several local higher education partners, several STEM certification programs were developed to increase science teachers' and administrators STEM content and pedagogical capacity. The various initiatives to support teachers' SCK and PCK on the implementation of the NGSS in the district are summarized in Appendix A.

Review of the Literature: Teacher Capacity and Student Achievement

This section presents the research related to teacher capacity and the impact on student learning in science. Over several decades, educational researchers (Darling-Hammond & McLaughlin, 1995; NCTAF, 1996; Loucks-Horsley & Matsumoto, 1999; Guskey, 2003; Guskey & Yoon, 2009; Weiss & Pasley, 2006; Supovitz & Turner, 2000; Darling-Hammond et al., 2009; Cohen & Hill, 2000; Garet et al., 2001; Fishman, Marx, Best, & Tal, 2003; Loucks-Horsley et al., 2010) have studied the professional learning experiences of teachers and administrators in an attempt to identify practices that are effective in increasing student achievement in science. This study proposes to build upon this body of research to focus specifically on elementary science teachers and administrators and their capacity to successfully support the implementation of the NGSS in the district. In this section, the following relevant topics to this research are reviewed: (a) teacher capacity, (b) the use of models and associated SEPs to support sense-making in the NGSS classroom, and (c) development and use of models as an anchor practice for sense-making.

Elementary Teacher Skills and Dispositions

Debates of what makes a good science teacher and what capacities, defined as knowledge, skills and dispositions, teachers need to be good teachers have been the evolving question for educational institutions and society at large (Clevenger-Bright & McDiarmid, 2008). Historically, in the United States, the focus has been on teachers' knowledge, skills, and dispositions (Clevenger-Bright, 2008), and the significance of the term "teacher capacity" has increasingly become a national competitive concern. Rapid industrialization and urbanization, the Soviet Union launch of the Sputnik satellite in 1957, and the 1983 publication of the National Commission on Excellence in Education's report *A Nation at Risk* have contributed to the evolution of the term "teacher capacity" in response to changing social, economic, political, science, technology, engineering and mathematics agendas (Cochran-Smith et al., 2008). The 2008 *Handbook of Research on Teacher Education* defines teacher capacity as "a teacher's knowledge, skills, and dispositions." With the long-standing conversations of what teachers need to know, to be able to do, and care about and debates among policymakers, researchers, critics, and teacher educators, these three broad constructs of the *Handbook of Research on Teacher Education* will be used to define teacher capacity with respect to teaching and learning of science in the elementary grades:

Knowledge: This includes subject matter, pedagogical content knowledge, curriculum, pedagogy, multicultural, historical, philosophical, sociological and psychological educational foundations, policy context, diverse learners to include students with disabilities and their cultures, technology, child and adolescent development, group processes and dynamics, theories of learning, motivation, and assessment systems.

Skills: This includes planning, organizing, and delivery of instruction, using appropriate and relevant instructional materials and technology, managing the learning environment, monitoring and evaluating learning, collaborating with colleagues, parents, and community partners.

Disposition: This includes beliefs, attitudes, values, and commitments of the teachers toward teaching science.

Teachers' science content knowledge (SCK). Most U.S. elementary science teachers are hired as certified generalists to teach all subjects in the K-5 setting (Lee et al., 2008; Raizen & Michelsohn, 1994; Tilgner, 1990). Most may have taken a few undergraduate or graduate science courses to obtain their teaching certification that satisfies the highly qualified (HQ) teacher definition for most states (MSDE, 2016). However, most do not have sufficient Science Content Knowledge (SCK) and are not sufficiently prepared to teach science subject matter nor do they have the scientific skills to feel confident about teaching science regularly (Lee et al., 2008; Raizen & Michelsohn, 1994; Tilgner, 1900). Moreover, a teacher's difficulty in asking and answering science questions is a function of his or her limited SCK (Roychoudhury & Kahle, 1999). These teachers' lack of SCK and insecurity may be attributed to general disinterest in, lack of exposure to, or intimidation by science content (Buczynski & Hansen, 2010).

Since teachers are seen as the single most important variable for producing student learning (Porter, 2012), teacher's science content knowledge (SCK) would be an asset in increasing student achievement (Heller et al., 2012; Cohen & Hill, 2000). Very often, SCK is cited as the root cause of the inability of teachers to teach science effectively (Fleer, 2009). Moreover, "variations in teachers' scientific knowledge and understanding have been identified as the main factor responsible for differences in the quality of elementary science teaching (Shallcross et al., 2002)." Some recent studies also demonstrated that elementary school teachers tend to have major gaps in their SCK, and that these gaps are major obstacle to effective teaching (Nowicki et al., 2013). However, very little research is available on how to improve practicing teachers' overall SCK (Fleer, 2009; Heller et al., 2012; Shallcross et al., 2002) measures or impact on classroom practice or student achievement (Porter, 2012).

Elementary teachers' pedagogical content knowledge (PCK). The term "pedagogical content knowledge" (PCK) was introduced by Shulman in 1986 as a way of understanding effective instructional practices for teaching specific subject matter in ways that students can understand (Shulman, 1986; Ben-Peretz, 2011; Kaya, 2009). More specifically, PCK is the knowledge that teachers use in transforming subject matter into forms that are comprehensible to students (Grossman, 1990; Shulman, 1987). Juttner et al. (2013) demonstrated from their research that SCK and PCK are two separate constructs. Similarly, some researchers argue that without strong SCK, strong PCK is impossible to achieve (Kaya, 2009; Van Driel et al., 2002). In a study of Turkish 10^{th}

grade students on the views of the nature of science, eight out of 14 items showed that teachers and students views were statistically similar, suggesting that SCK can have a direct effect on student learning (Dogan & Abd-El-Khalick, 2008).

Shulman uses the historical medical analogy of domain-specificity and clinical diagnosis to argue the case for moving away from behavior-based process-product research to teacher thinking, teacher knowledge, teacher decision-making, and teachers' conceptions of their subject matter and how these factors are related to how they performed. Shulman's PCK research on the multi-year *The Teacher Knowledge Project* on the domain specificity and contextualization of teacher knowledge, led to the design and development of the yearlong portfolio-based National Board Assessment. In this assessment, teachers demonstrate their knowledge at the intersection of content and pedagogy, what they needed to know and be able to do in order to teach the content and skills of the curriculum to students of different ages and background (Shulman, 2015). As Shulman stated, "it was PCK on steroids." From *Signature* Pedagogies (Shulman, 2005), the teaching and the preparation of teachers, shares many features with other learned professions such as lawyers, engineers, clergy, physicians, nurses and business leaders. He argues that all professions are domain specific. For example, what does it mean to act and think like an engineer or a scientist?

A consensus model of PCK was proposed to support science teachers' capacity on the implementation of the NGSS content knowledge which includes the three dimensions, the science and engineering practices used to generate knowledge, the disciplinary core ideas, and the recognition of the crosscutting concepts (Berry, Friedrichsen, & Loughran, 2015). This model includes teacher beliefs, such as the nature of science, motivation, dissatisfaction, efficacy, or risk-taking will act as amplifiers and filters in designing three-dimensional lessons that simultaneously integrate all three dimensions of the NGSS (Gess-Newsome, 2015).

The following are the teaching skills and attributes, or key ingredients, termed the "secret sauce" (pp. 56-57) identified by the 24 researchers at the 2012 PCK summit as well as other key factors needed in order for K-5 teachers to effectively teach science:

(a) *intertwine science learning with science teaching, provide a high-quality curriculum for teacher learning that models exemplary instruction for science learning* to include multi-modal learning opportunities such as reading, writing, discourse, individual, small group, whole group, with a focus of the science and engineering practices to include asking questions, developing models and explanations, and engaging in scientific argumentation, and

(b) *push for deep conceptual understanding of both the science and science teaching, leverage collaborative sense making and foster a community of professionals*.

Other key factors needed for effective science teaching include: adequate instructional time (Banilower et al., 2013; Trygstad et al., 2013; Nollmeyer, 2014; Bybee, 2013; Griffith, 2009; Hayes, 2014), an aligned curriculum with materials and equipment (Trygstad et al., 2013; Bybee, 2014), central office and school-based administrators' support in building instructional capacity (Griffith, 2009; Brogdon, 2015; NSTA, 2013; Wilson, 2013), and *Understanding by Design* (Wiggins & McTighe, 2005) application to the backward design of the 5E instructional Model (Bybee, 2015) and assessment processes.

Using the SEPs to support sense-making in the NGSS classroom. In this section, the SEPs are referenced in a general context in support of sense-making in the science classroom. The use of models as the anchor practice for the purpose of constructing explanations was the focus of this research. Two research-based practices' survey instruments that were adapted for my study were also discussed. Currently, there is no established comprehensive survey instrument with a clearly defined set of items to capture how well teachers are implementing both NGSS science and engineering practices (SEPs) and other relevant instructional practices with clearly defined sets of items (Hayes, Lee, DiStefano, O'Conner, & Seitz, 2016). However, two survey instruments were developed and tested in prior research related to teacher practices specific to some of the NGSS Science and Engineering. The *Science Instructional Practices* (SIPS) instrument (Hayes, Lee, DiStefano, O'Conner, & Seitz, 2016) and the *Operationalizing the Science Practices Teacher Questionnaire (SPTQ) User Guide* (Banilower, Hayes, Jaffri, & Egeland, 2016). The authors of the SIPS and SPTQ survey instruments granted the researcher permission to use and adapt items from both survey instruments.

As mentioned earlier, emphasis on the SEPs is highly grounded in what current research says about the successes and limitations of prior inquiry classrooms. The use of the SEPs to support sense-making in the classroom can be seen as a kind of Inquiry 2.0, where it serves as a second wave that articulates more clearly what successful inquiry looks like when it results in building scientific knowledge (NRC, 2012; NGSS Lead States, 2013; Schwarz, Passmore, & Reiser, 2017). For example, in order to test and confirm or disconfirm a hypothesis, traditional inquiry classrooms typically allow students to explore the relationship between two variables (e.g., how the mass of a toy car affects its stopping distance down an inclined plane), in this scenario, the notion of sense-making is not taking place in an ongoing process of questioning, developing, and refining explanatory knowledge about the world. The use of SEPs as a major instructional tool in the NGSS classroom is an attempt to move beyond inquiry where teachers can enable their students to investigate and make sense of phenomenon in the world by building and applying explanatory models, and designing solutions for problems. This reform in teaching practice is the fundamental goal on the NGSS and should be the core and cultural norm of what happens in science classrooms (Schwarz, Passmore, & Reiser, 2017).

In traditional inquiry classrooms Planning and Carrying Out Investigations (practice 3) and Analyzing and Interpreting Data (practice 4) were norms, however, the NGSS SEPs moved beyond these two to include other practices such as Developing and Using Models (practice 2) and Constructing Explanations (practice 6). The National Science Education Standards of 1996 attempted to include this practice, but did not succeed (NSES, 1996; NRC, 2001). The inclusion of practice six allows for students to articulate why something happens. Since students will have different ideas of why something in the world works, they will need to develop, use, and evaluate models (practice 2) to come to consensus by Engaging In Argument From Evidence (practice 7). During this interactive process, students will ask explanatory questions (practice 1) that will arise from making sense of their findings or consensus models. Hence, the culture of a sense-making classroom can be seen as a dynamic one where students are highly engaged in the SEPs to figure out the “how’s” and “why’s” of the workings of the natural and designed world (Schwarz, Passmore, & Reiser, 2017). For example, an observer should walk into a sense-making NGSS classroom and ask, "What are you trying to figure out right now?" The culture of the classroom should the intellectually clearer to everyone, including the teacher. Rather than stating, "We are learning about evaporation and condensation," students should be able to say, "We are trying to figure out why water disappears from an open container left in the sun or why water droplets appear on a cold soda can after sitting on the kitchen table." Another critical feature that will support a teacher's successful use of the SEPs in a sense-making classroom is the actual classroom culture itself. Students should be able to work together through social interactions and discourse to share and evaluate competing ideas, critique one another's ideas, and reach consensus as a classroom community (Berland, et al., 2016; Schwarz, Passmore, & Reiser, 2017).

Development and Use of Models as an Anchor Practice in Elementary Classrooms

In this section, the focus is on Development and Use of Models (practice 2) as an anchor practice for all the other seven SEPs (as seen in Figure 5), the lack of Development and Use of Models in elementary classrooms and what should a modeling NGSS classroom look like. As mentioned earlier, several researchers have supported the notion that Development and Use of Models is a central SEP that motivates, guides, and informs the other seven SEPs and brings them into a deeper and broader perspective for sense-making (Kenyon, Schwarz, & Hug, 2008; Schwarz et al., 2009; Schwarz, Passmore, & Reiser, 2017). One natural reciprocal connection that follows the Development and Use of Models is Constructing Explanations (practice 6). If students are going to account for how something works in the world, then they must develop an explanation of how their model works and communicate their ideas as a community. The literature uses terms such as "explanatory models" or "model based-explanations." Some researchers assert that models and explanations are different (Schwarz, Passmore, & Reiser, 2017; Kenyon, Schwarz, & Hug, 2008).

Several researchers assert that the practice of using models in elementary classrooms is rare and often reserved for older learners and when it occurs, it is primarily used for illustrative or communicative purposes, thus limiting the epistemic richness of this SEP (Berland et al., 2016; Windschitl, Thompson, & Braaten, 2013; Schwarz et al., 2009; Forbes, Zangori, & Schwarz, 2015; Schwarz, Passmore, & Reiser, 2017). However, once the culture of modeling is established in everyday elementary classrooms, students develop sophisticated explanatory models for observed phenomena. For example, Schwarz et al. (2009) found that 5th grade students engaged in modeling practices around the phenomena of evaporation and condensation, with sufficient teacher support, moved from illustrative to explanatory models, and developed increasingly sophisticated views of the explanatory nature of models, shifting from models as correct or incorrect to models as encompassing explanations for multiple aspects of the phenomena of evaporation and condensation. Students were also able to evaluate and compare other students' models in order to determine which aspects to include in the consensus model. Several other modeling researchers also observed similar findings (Kenyon, Schwarz, & Hug, 2008; Forbes, Zangori, & Schwarz, 2015; Windschitl & Thompson, 2013).

Several studies also identify major barriers and challenges to this reform approach, these include, existing culture of "school science" (defined as learning that involves accepting information from books, teachers or empirical evidence, without distinguishing between them), new reform-based curriculum structures, and students' and teachers' beliefs and expectations of these shifts (Berland & Reiser, 2009; Jimenenez-Aleixandre et al., 2002; Schwartz et al., 2009). Moreover, Berland and Reiser (2009) assert that shifting current classroom practice to a sense-making one may result in attitudes, expectations and beliefs arising from traditional schooling, on one hand, with the emerging understandings associated with modeling as a sense-making practice.

On the other hand, several modeling research findings assert that the practice of Developing and Using Models can provide an anchor for engaging in all the other seven SEPs in a NGSS classroom, thereby supporting the shifts, implications and vision of the NGSS (Schwarz, Passmore, & Reiser, 2017; Kenyon, Schwarz, & Hug, 2008; Schwarz et al., 2009; Forbes, Zangori, & Schwarz, 2015; Windschitl & Thompson, 2013). Schwarz, Passmore, and Reiser (2017) distinguish two types of modeling; what we think *about* models and what we think *with* models. Broadly speaking, what we think *about* models involves the intellectual work of deciding what goes into or what does not go into a specific model. The overall modeling practice involves students' engagement in developing a model that supports aspects of a theory and evidence, evaluating the model against empirical evidence and theory, and revising the model to enhance explanations and predictions. When students are thinking *about* models, they are constantly wondering about the component parts of a system and trying to figure out what are the key parts and how they are related to each other.

One of the major goals of the NGSS is change teachers' practice to support students "*thinking with*" models (NRC, 2012; NGSS Lead States, 2013; Schwarz, Passmore, & Reiser, 2017). To support this major goal of the NGSS, teachers will need to support a “model-based reasoning” classroom culture, where students are constantly involved in the use and application of models to predict and explain phenomena in a variety of ways. For example, in a 5th grade classroom, one of *the Performance Expectations* for Physical Science, Matter and Its Interactions (5-PS1-1), states that students should be able to, (develop a model to describe that matter is made up of particles too small to be seen.” Hence, in an active modeling classroom that is investigating the phenomena of evaporation and condensation through a homemade plastic two liter soda bottle solar distillation apparatus (solar still), should be able to construct and *use* their models about these phenomena to explain the functioning of the solar still. Hence, in a NGSS classroom, the practice of modeling is seen as an iterative cycle of three steps – development, testing and revising of models, that are guided by the goals of sense-making discussed earlier. From a curricular perspective, Figure 6 summarizes of what an iterative instructional modeling sequence for an elementary curriculum would look like.

Sequence	**Description**
Anchoring phenomena	Introduce driving question and phenomena for a particular Concept. Use a phenomenon that may necessitate using a model to figure it out.
Construct a model	Create an initial model expressing an idea or hypothesis. Discuss purpose and nature of models.
Empirically test the model	Investigate the phenomena predicted and explained by the model.
Evaluate the model	Return to the model and compare with empirical findings. Discuss qualities for evaluation and revision.
Test model against other ideas	Test the model against other theories, laws.
Revise the model	Change the model to fit new evidence. Compare competing models, and construct a consensus model.
Use model to predict or explain	Apply model to predict and explain other phenomena.

Figure 6. Example of an instructional modeling sequence for an elementary curriculum. Adapted from Schwarz et al. (2009), p. 638.

Research-based Practices' Instruments

SIPS: The SIPS instrument was developed to survey teachers regarding their use of a range of science instructional practices necessary to support the NGSS. The survey is grouped into 5 instructional practices factors: instigating and investigation, data collection and analysis, critique, explanation and argumentation, modeling traditional instruction, prior knowledge, science communication, and discourse. The internal consistency of these factors was high, Cronbach's α ranged from .80 to .88 (Hayes et al., 2016). There are 31 questions in the final SIPS survey. The sets of survey items for each of the five key areas were rated on a 5-point Likert scale ranging from 1 (*Never*), 2 (*Rarely-a few times a year*), 3 (*Sometimes-once or twice a month*), 4 (Often), and 5 (*Daily or almost daily*). Hayes et al. assert, "The SIPS instrument is also critical for researchers and teacher educators interested in understanding instructional shifts in large samples of teachers, whether measuring results from professional development or the implementation of science education policies." The modified questions are captured in Figure 8 below.

SPTQ: This survey was developed by Horizon Research, Inc. (HRI), (Banilower, Hayes, Jaffri, & Egeland, 2016), with a grant from the National Science Foundation. The instrument was developed to be used as part of a national large scale investigation on the extent to which classroom instruction aligns to the K-12 Science Education and the NGSS as a response to the NRC's 2013 report, *Monitoring Progress Toward Successful K-12 Education: A Nation Advancing,* which called for the development of a national indicator system that could be used to improve STEM education through quality science education and teacher capacity in the United States. This survey consists of two sets of closed-ended items, with a total of 41 items. The first set addresses the extent to which teachers' objectives for science instruction, include students gaining proficiency with the SEPs. The second set of items, which is more relevant to this study, assess how often teachers engage students in the SEPs during their science instruction. The elementary band for this set of NGSS aligned practices questions, demonstrated a high internal consistency for all eight factors (practices), with a range of Cronbach's α from .80 to .92 (Banilower et al., 2016). The modified questions are captured in Figure 8.

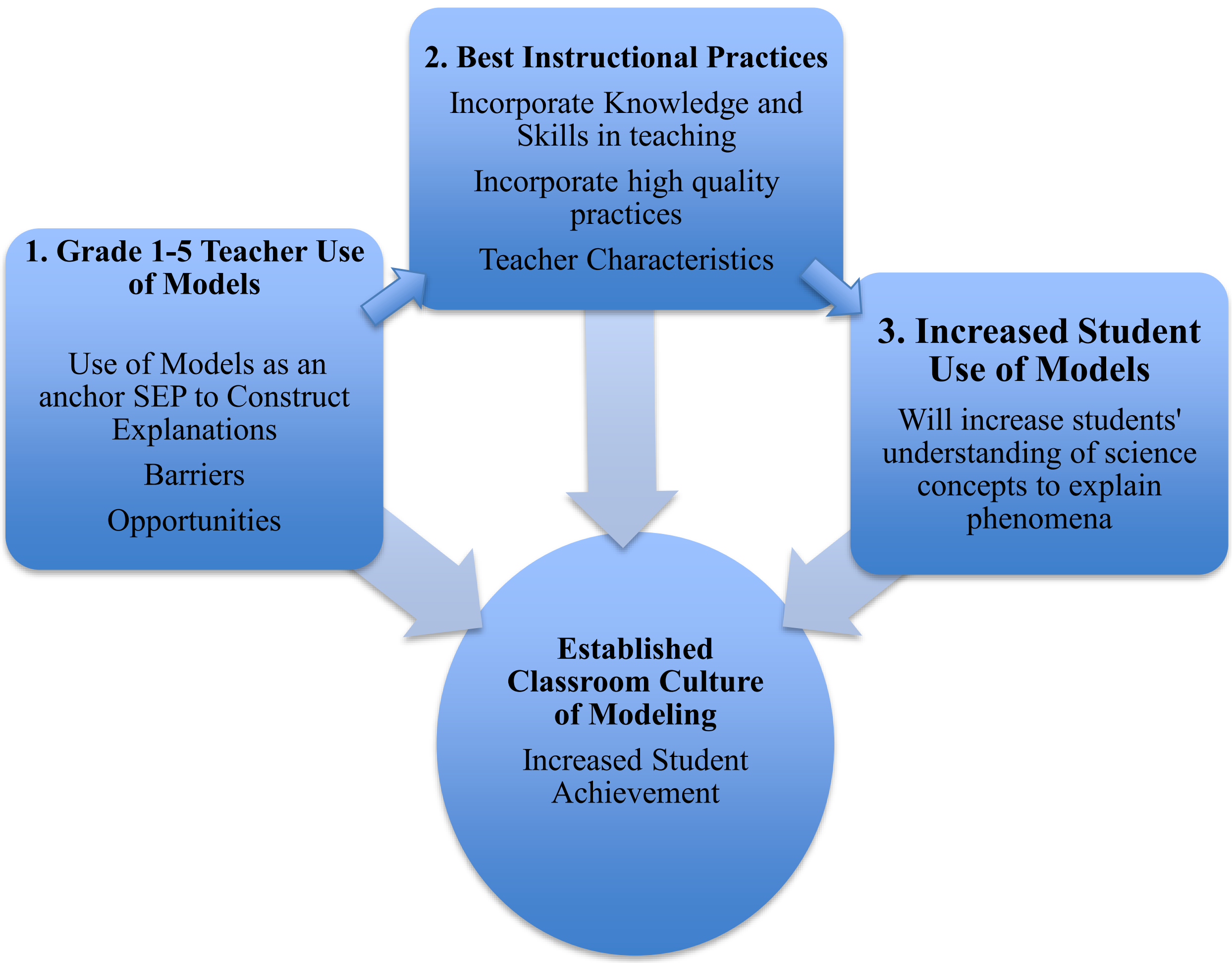


Figure 7. Conceptual Framework

In Figure 7, box 1 addresses the inputs of grade 1-5 teachers' use of models as an anchor SEP to construct explanations and what factors afford such use and barriers prevent such a use. Box 2 addresses the best practices, instructional activities, and teacher characteristics that support their use of modeling in science instruction. Box 3 represents the intermediate argument-based outcome of increased student use of models will increase their understanding of science concepts in the construction of explanations to explain phenomena. Box 4 represents the long-term outcome of increased student achievement once a classroom culture of modeling is established in District Q.

Summary

We know from the research studies cited earlier that teacher quality is the single most important variable in affecting student achievement. We also know from past and current research, that grade 1-5 teachers may not necessarily possess the capacity to successfully implement a standards-based science curriculum such as the NGSS. Several factors such as lack of science content and pedagogical content knowledge, and relevant professional learning opportunities, administrator support, equity of resources to include science instructional time, aligned materials and equipment were cited in the research as root causes. The NGSS are a set of reform standards that will require our grade 1-5 teachers to engage their students in all three dimensions of these new standards and there is a gap in the literature regarding teacher use of the science and engineering practices, specifically scientific modeling in their instruction (Krajick & Merritt, 2012; Banilower, 2013; Forbes et al., 2015; Windschitl & Thompson, 2013; Riser, 2013; Lo et al., 2013; Schwarz et al., 2009; Schwarz, Passmore, & Reiser, 2017). Further elementary grade teachers have been shown to lack the PCK and experiences to guide students in these practices.

As discussed earlier, the district's 5th grade science scores on the 5th grade state science assessment lag behind most districts in the state. With the implementation of the more rigorous and internationally benchmarked new NGSS and new State Integrated Science Assessment in the district, there are significant instructional shifts that teachers will have to embrace and practice in order to be successful in a NGSS classroom. These instructional shifts include the teaching of science using the 3 dimensions of the NGSS to help students make sense of their world through phenomenon-based instruction and the culture of sense-making, especially using modeling as an anchor SEP as a constant in everyday science classroom instruction. In order for the district to provide the resources such as professional development that is targeted on NGSS and designed to build specific instructional competencies, the district needs to better understand teachers' current practices. In addition, some researchers argue that teacher characteristics such as use of appropriate methods, science content knowledge, and use of the science and engineering practices should be part of their constellation of characteristics that contribute to effective science teaching; however, the research on this attribute is lacking (Wilson, Floden, & Ferrini-Mundy, 2001; NRC, 2001; Bybee, 2014). Therefore, the purpose of this study was to document the extent to which grade 1-5 teachers in District Q report the use of models for the purpose of constructing explanations during science instruction. Results of this study can inform the design and development of relevant, meaningful and differentiated professional learning opportunities for teachers in District Q that are focused on the three dimensions of NGSS.

Section 2: Methodology

This section presents the details regarding the specific research questions and methods used to address the purpose of the study.

Research Questions

The following research questions were addressed by my study:

1. How frequently do grade 1-5 teachers report using models as part of their science instruction?
2. What barriers do grade 1-5 teachers report to their ability to support students' construction of models?
3. Is there a relationship between the personal characteristics and demographics of teachers and frequency of reported use of supporting students' use of models in their science instruction?

Design and Methods

This was an exploratory study that focused on the teachers' reports of the extent to which they integrated the SEPs (specifically modeling) of the NGSS in their daily science instructional practice. The study utilized a 15-minute web-based survey administered through Qualtrics survey software. Since this study is designed to provide a snapshot at a particular time on the use of the SEPs and other PCK practices by the grade 1-5 teachers in the district, a survey was considered to be an appropriate tool for collecting the data (Gay, Mills, & Airasian, 2006; Kelley, Clark, Brown, & Sitzia, 2003). Kelley et al. (2003), further assert that the use of a survey in an exploratory and descriptive study is very appropriate if the aim is to examine a situation by describing important factors associated with a situation, such as demographic, socio-economic, events, behaviors, attitudes, experiences, and knowledge. Furthermore, an anonymous survey such as the one used in this study will maintain confidentiality and overcome the problem of response sets (Gay et al., 2006). Additionally, another advantage of using a survey tool for this research is that it offered a breath of coverage on many participants and was able to produce a large amount of data in a short amount of time in a low cost environment (Kelley et al., 2003). The data obtained from the questionnaire were used to establish relationships and associations between the independent variables such as teachers' instructional practices, demographics and challenges on the use of modeling in science instruction (the dependent variable).

Survey instrument. The survey used in my study is in Appendix B. It is comprised of four sections. The first section of the survey asks general demographics questions, followed by three other sections that specifically ask relevant questions on *instructional approaches on the development and use of models, measuring instructional practices to support the shifts and demands of teaching NGSS, and barriers on the use of modeling* in grade 1-5 science teachers' classrooms. The survey contained 38 questions.

Part A of the survey contains seven demographic items: school type, grade level taught, years of teaching experience, instructional arrangement, science courses completed in college, position, and estimated weekly instructional time spent on science, and common core. Part B of the survey contains eight items that ask teachers to report on the use of various instructional approaches on the development and use of models in their classrooms. These questions were adapted from previous surveys (Hayes, Lee, DiStefano, O'Conner, & Seitz, 2016; Banilower, Hayes, Jaffri, & Egeland, 2016). Data from this section was analyzed to provide the answer to research question one; how frequently do grade 1-5 teachers report using modeling as part of their science instruction. Part C of the survey includes seventeen items that asked grade 1-5 teachers to report on instructional practices on the development and use of models. Data from this section was analyzed to determine if there was a relationship between the personal characteristics and demographics of teachers and frequency of reported use of supporting students' use of models in their science instruction. The final section, part D of the survey includes six questions that asked respondents to identify these six statements as not a barrier, mostly not a barrier, neutral, somewhat a barrier, and major barrier toward the development of a modeling culture in their classroom and school.

Figure 8 below indicates the final survey items that correspond to specific research questions and which items were adapted from SIPS or the Sciences Practices Teacher Questionnaire (SPTQ).

Research Questions	**Items**	**Source**
General Demographics	*Participants were asked to check the appropriate box for demographic information that applies to them.*	Researcher
1.	Informed Consent?	Researcher
2.	What school type describes where you teach?	Researcher
3.	What grade band do you teach?	Researcher
4.	What is the overall number of years in teaching?	Researcher
5.	Which of the following best describes how science is taught at your school?	Researcher
6.	What other positions do I hold at my school?	Researcher
7.	What science courses have I completed in college?	SPTQ-modified by researcher to reflect NGSS domains

8.	During a typical week, about how many hours do you teach the following content (Science, Mathematics, English Language Arts, and Social Studies?	Researcher
Research Question 1: How frequently do grade 1-5 teachers report using modeling as part of their science instruction?	*A 5-point Likert Scale, similar to SIP or SPQ was used. Participants were asked to rate how often they use these NGSS instructional approaches on the development and use of models?*	SIPS, SPTQ or Researcher
1.	Use existing models to construct explanations of phenomenon	SIPS, modified by researcher
2.	Create a physical model of a scientific phenomenon (like creating a representation of the water cycle. Graphic provided.	SIPS
3.	Develop a conceptual model based on data or observations (model is not provided by textbook or teacher, for example student generated model of evaporation or condensation). Graphic provided.	SIPS
4.	Represent relevant components of a phenomenon when developing models. Graphic provided.	SPTQ, modified by researcher
5.	Discuss how scientific models and explanations are based on existing evidence	SPTQ
6.	Use simulation models (such as Concord Consortium or PhET Simulations) to generate evidence to support a scientific explanation of a phenomenon.	SPTQ, modified by researcher
7.	Revise scientific models based on additional evidence	SPTQ
8.	Identify the strengths and limitations of a scientific model	SPTQ
Answers to these questions will contribute to the data analysis for Research Questions 1 and 3.	*A 5-point Likert Scale, similar to SIP or SPTQ was used. Participants were asked to rate how often they do each of the following instructional practices to support the shifts and demands of teaching NGSS?*	SIPS or SPTQ
1.	Have students generate or identify questions or predictions to explore real world phenomena	SIPS
2.	Have students design or implement their own investigations	SIPS
3.	Have students write about what	SIPS

	was observed and develop models to explain why it happens	
4.	Provide direct instruction to explain science concepts	SIPS
5.	Demonstrate an experiment and have students watch	SIPS
6.	Use activity sheets to reinforce practices or content	SIPS
7.	Define vocabulary words before a lesson is taught	SIPS, modified by researcher
8.	Talk with students about things they do at home that are similar to what is done in science classes (e. g., measuring, boiling water	SIPS
9.	Have students work in small groups	SIPS
10.	Encourage students to explain science concepts to one another	SIPS
11.	Use the district's curriculum to teach NGSS lessons	Researcher
12.	Use the SEPs to teach science	Researcher
13.	Use the claim, evidence, and reasoning model to generate scientific explanations	Researcher
14.	Demonstrate what modeling looks like in my classroom	Researcher
15.	Use modeling to engage students in the other seven SEPs such as constructing explanations or argumentation	Researcher
16.	Have students revise their own and others' models in an effort to develop consensus models	Researcher
Research Question 2: What barriers do grade 1-5 teachers report to their ability to support students' construction of models?	*A 5-point Likert Scale, similar to SIP or SPTQ was used. Participants were asked to rate each statement as not a barrier, mostly not a barrier, neutral, somewhat a barrier or a major barrier?*	Researcher
1.	School culture only focuses on common core Mathematics and RELA	Researcher
2.	Limited instructional time	Researcher
3.	Limited instructional materials to include digital devices and science equipment	Researcher
4.	My level of understanding of the expectations of NGSS	Researcher
5.	My level of understanding of the district's science instructional resources (to include curriculum)	Researcher
6.	Inadequate Professional	Researcher

	Development opportunities to help me understand the NGSS Science and Engineering Practices	
7.	Inadequate administrator support for science instruction	Researcher

Figure 8. Adapted from SIPS and the Sciences Practices Teacher Questionnaire (SPTQ).

Survey pilot testing. The survey was piloted using four NGSS content experts and 20 grade 1-5 target teachers who were excluded from receiving the final survey. Each of the individuals was asked to answer the questions on the survey and provide feedback on the average completion time, clarity and relevance of the questions and overall usability of the survey tool. Once feedback was received, the survey tool was revised and finalized to reflect the necessary recommendations of the pilot participants. Revisions from the pilot included adding visuals to enhance the grade1-5 teachers' understanding of the various modeling items in Question nine, including a physical, a conceptual (student-generated), and a simulation model.

Selection of Participants

For purposes of this exploratory quantitative study, all the district's grade 1-5 full-time teachers of record from all the elementary and K-8 schools were eligible to participate in the survey. Since the researcher is focusing on the use of modeling in the district's elementary grades, surveying all the grade 1-5 teachers is appropriate for this study (Hayes et al., 2016; Banilower et al., 2016). District Q has 118 elementary schools and 16 K-8 schools, including specialty schools. The researcher obtained the emails of 1,200 grade 1-5 teachers from 134 schools from District's Q public information website. This email list was used to disseminate the web-based online survey. In an effort to increase the response rate for the second and final week of the survey, and in addition to a reminder email to the participants (see Appendix G), an email with the survey link was shared with 134 elementary and K-8 principals of schools with target teachers to distribute to their grade 1-5 teachers, encouraging them to participate in the survey. A copy of the email to principals is in Appendix C.

Additionally, participants received an incentive to maximize response rate of the survey. Eligibility for the incentive required that the participants complete the survey within the required timeline. In order to maintain the anonymity of the schools and participants' data, a URL was created at the end of the first anonymous survey in Qualtrics. This URL redirected participants to a secondary survey, where additional information such as email address and school were obtained. The personal information collected in the secondary survey was not be associated with the responses in the first survey, hence maintaining anonymity.

Data Collection Procedures

Once the IRB from the University of Maryland and from District Q were approved, an introductory email of my research containing a cover letter, the Informed Consent and final survey link were sent to all the schools' grade 1-5 science teachers in District Q (see Appendix E for a copy of the email to participants). The cover letter also contained information on the purpose of the study, how the data will be collected, benefits, confidentiality, possible risks, incentives and the informed consent process (see Appendix D for a copy of the cover letter). Participants were also reminded that their responses were anonymous and their personal information would not be captured in their responses.

Once participants clicked on the link to the survey, they were taken to the Informed Consent Form (Appendix F). Participants were prompted to read the consent form that includes information such as purpose of the study, procedures, potential risks, confidentiality, incentive, participants' rights, and key personnel information for questions regarding this research, from the approved University of Maryland's IRB Form one. Individuals were asked to indicate their consent and if they do so, were directed to complete Parts A–D of the survey. If an individual did not consent to participate, they were directed to the end of the survey and the survey closed.

The survey was available for two weeks and participants were able to assess the survey link as many times as needed until they have completed the survey.

Study timeline. The timeline for the study is outlined below:

Date	Proposed Activity
January 1-April 28, 2017	Development and testing of Survey tool
March 27-April 28, 2017	Identifying & obtaining all grade 1-5 science teachers' emails in the district
September 17-29, 2017	Administration of the survey tool
September 25, 2017	Email reminder sent to participants and email assistance sent to principals
September 29-October 27, 2017	Analysis of data

Analyses Procedures

In this section, I describe the procedures used to analyze the data obtained in Qualtrics. The data from the Qualtrics survey software were exported to SPSS for analysis. For research questions 1 and 2 descriptive statistics was used to report the frequency, percentage, mean and standard deviation for the aggregate population and further disaggregated by grade bands – grades 1-2 and 3-5 for the same descriptive statistics such as elements of use frequency, percentage, and mean.

Since research question 3 focused on relationships between the personal characteristics and demographics of teachers and frequency of reported use of supporting students' use of models in their science instruction, Pearson Product Moment correlations were computed and MANOVAs were used to determine differences between teachers' use of modeling (dependent variable) and several independent variables on teacher characteristics and demographics such as grade bands, years of teaching, science courses completed in college, school type (Title I or Non-Title I), various instructional practices and amount of instructional time.

Human Subject Review and Confidentiality

To meet the University of Maryland's IRB guidelines concerning research with human subjects, and District Q's guidelines, the following processes were used to protect the participants in the study as well as the University of Maryland and District Q.

- All participants were provided with a cover letter describing the purpose of the study (see Appendix D).
- All participants agreed with the informed consent electronically before completing the survey (see Appendix F for a copy of the informed consent).

- All data obtained from participants were confidential and anonymous.
- Additionally, the collected data will be stored for three years in a HIPPA-compliant, secured database on a password-protected flash drive and computer. This procedure will minimize any potential loss of confidentiality and anonymity.

As mentioned earlier, for incentive purposes, in order to maintain the anonymity of the schools and participants' data, a URL was created at the end of the survey. This URL redirected participants to a secondary survey, which asked for additional information such as email address. The personal information collected in the secondary survey was not associated with the responses in the first survey, but the researcher used the information of the secondary survey to generate the winners for the fifty \$10 Amazon.com gift cards. One hundred and seventy-eight participants responded that they wanted to be selected in the raffle for the fifty \$10 Amazon.com gift card. These participants' emails were numbered from 1 to 178 and this range was entered in a random number selector App with an output for 50 random numbers. The selected numbers were then matched to the appropriate numbered emails and electronic gift card was emailed to each of the 50 winners.

Summary

Section 2 provided an overview of the researcher's study that was intended to explore teachers reported use of instructional practices (specifically the use and development of models) for the NGSS implementation and initiative in grade 1-5 science teachers' classrooms in the district. The participants, procedures, and targeted population were also discussed. Specifics regarding the development and distribution of the final survey were also explained. Finally, a brief description of how the data were analyzed was also provided. In section 3, the results are presented, followed by the discussion and conclusions.

Section 3: Results, Discussion, and Conclusions

In this section, the findings are presented from the analysis of the data collected through the online survey. In the first section, the general trends of the results are discussed. Next, is a discussion of findings related to each of the three research questions. This is followed by conclusions drawn from this study and implications for future recommendations for District Q.

General Overview of Results

A total of 1,200 grade 1-5 teachers in the district were identified to take the survey. Of this sample, 357 teachers responded to the survey, this represents a 30% response. Two hundred and sixty-nine teachers completed all of the 38 questions in the survey. Only data from completed surveys were analyzed. The researcher had no way of identifying how many of the 134 schools participated but can report that from the secondary incentive survey, 87 schools were represented. Table 3 provides a description of the respondents.

Table 3a

Teacher Characteristics

Background Characteristics	Survey Options	Grades 1-5(f)	Grades 1-5(%)	Grades 1-2(f)	Grades 1-2(%)	Grades 3-5(f)	Grades 3-5(%)
	N = 269	269	100	121	45	148	55
School Type							
	Title I School	145	54	65	24	80	30
	Non-Title I School	124	46	56	21	68	25
Overall Years of Teaching							
	0- 5 years	71	26	42	16	29	10
	6-10 years	43	16	17	6	26	10

11-15 years	51	19	19	7	32	12
16-21 years	54	20	22	8	32	12
Plus 21years	50	19	21	8	29	11
How is Science Taught in Your School						
All Core Subjects	144	54	93	35	51	19
Departmentalized	124	46	28	10	96	36
Pull Out	1	0	0	0	0	0
Additional Positions Held						
Science Coordinator	37	14	7	3	30	11
Professional Development Lead Teacher	17	6	10	4	7	3
Classroom Teacher	215	80	104	39	111	41
College Science Courses						
All four domains- life science, earth and space science, physical science and engineering	81	30	30	11	51	19
Life science, earth and space science, and physical science	80	30	42	16	38	14
Life science, earth and space science	26	10	14	5	12	5
Life science	40	15	20	7.5	20	7.5
Earth and space science	4	1	3	0.7	1	0.3
Physical science	14	5	3	1	11	4
Engineering	0	0	0	0	0	0
None of the above	24	9	9	3	15	6

Note. Total % Grade 1-5= % Grade 1-2 + % grade 3-5

As noted in Table 3a, 80% of the respondents were teachers, while 14% were elementary science coordinators (lead) and 6% were professional development lead teachers in their buildings. Over a fourth of the sample was comprised of new teachers (0-5 years) in District Q. A little over half (54%) of the teachers taught in self-contained classrooms (teaching all content) while 46% taught in departmentalized setting (a science specialist teaching science) for grades 3-5

Eleven percent of grade 1-2 and 19% of grade 3-5 teachers reported that they completed college courses that addressed all 4 domains (earth and space science, life science, physical science and engineering) of NGSS, while 16% of grade 1-2 and 14% of grade 3-5 said that they completed 3 domains (earth and space science, life science, physical science). Sixty-one percent of the respondents reported that they completed college courses that addressed at least one to three domains of NGSS. Zero percent of teachers reported taking a college engineering course. Nine percent of teachers reported that they have not taken any science college courses.

Table 3b

Teacher Characteristics

Background Characteristics	Survey Options	Grades 1-5(f)	Grades 1-5(%)	Grades 1-2(f)	Grades 1-2(%)	Grades 3-5(f)	Grades 3-5(%)
Hours Teaching Common Core Mathematics							
	1 hour or less	40	15	4	1	36	14
	1-2 hours	28	10	19	7	9	3
	2-3 hours	8	3	4	1.5	4	1.5
	3-4 hours	22	8	11	4	11	4
	More than 4 hours	171	64	83	31	88	33
Hours Teaching Science							
	1 hour or less	48	18	26	10	22	8
	1-2 hours	54	20	34	11	20	9

	2-3 hours	52	20	29	11	23	9
	3-4 hours	51	19	21	8	30	11
	More than 4 hours	64	23	11	4	53	19
Hours Teaching Common Core RELA							
	1 hour or less	83	30	3	1.5	80	28.5
	1-2 hours	25	9	15	22	10	3
	2-3 hours	7	3	6	2	1	1
	3-4 hours	15	6	7	3	8	3
	More than 4 hours	139	52	90	34	49	18
Hours Teaching Social Studies							
	1 hour or less	130	48	48	18	82	30
	1-2 hours	72	27	38	14	34	13
	2-3 hours	46	17	26	10	20	7
	3-4 hours	15	6	7	3	8	3
	More than 4 hours	6	2	2	0.5	4	1.5

Note. Total % Grade 1-5= % Grade 1-2 + % grade 3-5

From Table 3b, 64% of the grade 1-5 teachers report that they spend the majority of their instructional time (more than 4 hours) teaching mathematics, compared to 52% for RELA and 23% for science. Only 4% of grade 1-2 teachers reported teaching science for more than 4 hours per week. Additionally, 38% of the grade 1-5 teachers reported teaching science for less than two hours per week.

Results for Each Research Question

In the following section, the findings pertaining to the research questions are presented. Research question 1 focused on how frequently grade 1-5 teachers report using models as part of their science instruction. In the survey, participants were asked to self-report on a 1-5 point Likert scale “how often do their students do each of the following in their science classes” with respect to instructional approaches on the development and use of models. Research question 2 focused on what barriers grade 1-5 teachers report to their ability to support students' construction of models. In the survey, participants were asked to rate 6 statements on a 1-5 point Likert scale (1 = not a barrier, 2 = mostly not a barrier, 3 = neutral, 4 = somewhat a barrier, and 5 = major barrier) as to what extent they are barriers to developing a modeling culture in their classrooms. Research question 3 focused on investigating if there are relationships between the personal characteristics and demographics of teachers and frequency of reported use of supporting students' use of models in their science instruction.

Research Question 1

Research question 1 asked: *how frequently do grade 1-5 teachers report using models as part of their science instruction.* Table 4 below presents the frequencies of model inclusion of responses for each of the 12 survey questions pertaining to modeling. The overall frequency of the participants' use of models was very low (mostly from *never* to *rarely* to *sometimes*) for all but one of the 12 modeling survey items. For example, 84% of teachers reported that the *never, rarely or sometimes* use simulations to create models of a scientific phenomenon and 85% reported that they *never, rarely or sometimes* revise scientific models based on additional evidence nor identify the strengths and limitations of a scientific model. Additionally, 76% of the teachers reported that they *never, rarely or sometimes* create a physical model of a scientific phenomenon and 63.5% reported that they *never, rarely or sometimes* use existing models to construct explanations of phenomena. Seventy-three percent reported that they *never, rarely or sometimes* developed a conceptual model based on data or observations. Of note is that only 35% of the teachers reported that the *never, rarely or sometimes* demonstrated what modeling looks like in the teachers' classroom.

Table 4

Teacher Frequency of Model Inclusion and Instruction

Modeling Strategy	Grades Level	Never	Rarely	Sometimes	Often	Daily	Mean	SD
Use Existing Models	Grades 1-2 (f)	9.00	32.00	46.00	28.00	6.00	2.92	1.00
	Grades 3-5 (f)	5.00	27.00	52.00	51.00	13.00	3.27	0.97
Create Physical Model	Grades 1-2 (f)	15.00	40.00	45.00	19.00	2.00	2.61	0.95
	Grades 3-5 (f)	6.00	37.00	61.00	36.00	8.00	3.02	0.94
Develop Conceptual Model	Grades 1-2 (f)	16.00	40.00	39.00	24.00	2.00	2.64	1.00
	Grades 3-5 (f)	7.00	35.00	59.00	37.00	10.00	3.05	0.97
Represent Relevant Components	Grades 1-2 (f)	19.00	27.00	51.00	21.00	3.00	2.69	1.02
	Grades 3-5 (f)	7.00	21.00	60.00	49.00	11.00	3.24	0.95
Discuss Scientific Models	Grades 1-2 (f)	10.00	29.00	53.00	25.00	4.00	2.87	0.95
	Grades 3-5 (f)	6.00	19.00	42.00	58.00	23.00	3.49	1.03
Use Simulated Models	Grades 1-2 (f)	42.00	45.00	21.00	11.00	2.00	2.06	1.02
	Grades 3-5 (f)	31.00	44.00	43.00	22.00	8.00	2.54	1.14
Revise Models	Grades 1-2 (f)	39.00	41.00	31.00	8.00	2.00	2.12	0.99
	Grades 3-5 (f)	22.00	46.00	50.00	23.00	7.00	2.64	1.06
Identify Strengths/ Limitations	Grades 1-2 (f)	38.00	44.00	27.00	12.00	0.00	2.11	0.96
	Grades 3-5 (f)	23.00	42.00	53.00	20.00	10.00	2.68	1.10
Write About Observed Models	Grades 1-2 (f)	4.00	20.00	43.00	46.00	8.00	3.28	0.93
	Grades 3-5 (f)	2.00	19.00	47.00	53.00	27.00	3.57	0.98
Demonstrate Modeling	Grades 1-2 (f)	2.00	11.00	33.00	46.00	29.00	3.74	0.98
	Grades 3-5 (f)	1.00	16.00	31.00	60.00	40.00	3.82	0.97
Modeling to Engage Students	Grades 1-2 (f)	8.00	20.00	42.00	36.00	15.00	3.25	1.08
	Grades 3-5 (f)	3.00	19.00	46.00	50.00	30.00	3.57	1.02
Revise Own and Others Models	Grades 1-2 (f)	20.00	29.00	47.00	20.00	5.00	2.68	1.07
	Grades 3-5 (f)	13.00	32.00	55.00	35.00	13.00	3.02	1.08

Note. Data is displayed by frequency of participants' survey reporting.

Research Question 2

Research question 2 focused on *what barriers do grades 1-5 teachers report to their ability to support students' construction of models.* In the survey, participants were asked to rate 7 statements on a 1-5 point Likert scale (not a barrier = 1, mostly a barrier = 2, neutral = 3, somewhat a barrier = 4 and, major barrier = 5) as to what extent they are barriers to developing a modeling culture in their classrooms. Scale 3, *neutral* from previous studies (Trygstad et al., 2013) can be interpreted as either as *somewhat a barrier* or *mostly not a barrier* for participants who are unsure of their choices, hence was not used in the analysis of the results. An average of 44% of the teachers rated all seven barrier statements as *somewhat a barrier and a major barrier*. Of note are the following rankings: limited instructional time ranked as the number one barrier (67%), followed by limited instructional materials to include digital devices and science equipment ranked as the number two barrier (59%), school culture only focuses on Common Core Mathematics and RELA ranked as the third barrier (52%), inadequate professional development opportunities to help teachers understand NGSS SEPs as the fourth barrier (40%), teacher level of understanding the expectations of NGSS and level of understanding of the district's science instructional resources ranked fifth (38%) and sixth (35%), respectively. Inadequate administrator support for science instruction ranked seventh (27%).

From the disaggregated barrier data (see Appendix H), a larger percentage of teachers report that these barriers are significantly greater in the grades 1-2 for instructional time (73%), teacher level of understanding the expectations of NGSS (53%), teacher level of understanding of the district's science instructional resources (48%) and inadequate administrator support for science instruction (38%).

Table 5
Teacher Perceived Barriers

	Not a Barrier	Mostly Not a Barrier	Neutral	Somewhat a Barrier	Major Barrier	Mean Rating	SD
My school culture only focuses on Common Core Mathematics and RELA							
Grades 1-5 (f)	47	25	57	89	51	3.27	1.348
Grades 1-5 (%)	17.5	9.3	21.2	33.1	19.0		
Limited instructional time							
Grades 1-5 (f)	36	25	29	80	99	3.67	1.397
Grades 1-5 (%)	13.4	9.3	10.8	29.7	36.8		
My level of understanding of the expectations of NGSS							
Grades 1-5 (f)	50	53	64	81	21	2.89	1.244
Grades 1-5 (%)	18.6	19.7	23.8	30.1	7.8		
My level of understanding of the district's science instructional resources							
Grades 1-5 (f)	54	57	65	71	22	2.81	1.256
Grades 1-5 (%)	20.1	21.2	24.2	26.4	8.2		
Inadequate Professional Development opportunities to help me understand the NGSS Science and Engineering Practices							
Grades 1-5 (f)	47	50	63	73	36	3.00	1.303
Grades 1-5 (%)	17.5	18.6	23.4	27.1	13.4		
Inadequate administrator support for science instruction							
Grades 1-5 (f)	78	38	79	45	29	2.66	1.339
Grades 1-5 (%)	29.0	14.1	29.4	16.7	10.8		
Limited instructional materials to include digital devices and science equipment							
Grades 1-5 (f)	30	33	48	83	75	3.52	1.315
Grades 1-5 (%)	11.2	12.3	17.8	30.9	27.9		

Research Question 3

Pearson Product Moment correlations were used to explore relationships between the personal characteristics and demographics of teachers and frequency of reported use of supporting students' use of models in their science instruction. MANOVAs were also used to determine differences between teachers' use of modeling (dependent variable) and several independent variables on teacher characteristics and demographics.

Table 6 presents the correlations coefficients. According to Gay, Mills, and Airasian (2006), correlation coefficients between +. 35 and +. 65 or between -.35 and -.65 represent moderate relationships. Hence, there is a moderate relationship between the hours of teaching science and the following components of modeling instruction: using existing models to construct explanations of phenomena (.355), creating physical models (.386), developing conceptual models (.352), representing the relevant components of a phenomenon when developing models (.341), and discussing how scientific models and explanations are based on existing evidence (.352). Not surprising, these results indicate that dedicating more instructional time to teaching science may increase use of modeling practices.

Table 6

Correlation Coefficients: Teacher Experience and Instructional Time

	Teaching Experience	Hours Teaching Science	Hours Teaching Mathematics	Hours Teaching RELA	Hours Teaching Social Studies
Construct Explanations	.042	.355**	-.083	-.190**	.069
Create Physical Models	.063	.386**	-.085	-.171**	.121*
Conceptual Modeling	.005	.352**	-.087	-.204**	.083
Represent Components	-.058	.346**	-.036	-.222**	.010
Discuss Models	-.006	.352**	-.042	-.265**	.030
Simulation Models	.080	.196**	-.092	-.208**	-.024
Revise Models	.040	.214**	-.103	-.216**	-.039
Identify Strengths/ Limitations	.054	.183**	-.090	-.188**	.017
Write About Models	-.004	.305**	-.087	-.243**	.040
Evidence and Reasoning	.117	.279**	-.112	-.292**	.060
Demonstrate Modeling	.027	.203**	-.027	-.120	.160**
Engage Students	.068	.292**	-.051	-.166**	.128*
Revise Models	.072	.235**	-.077	-.173**	.104

Note. Correlations between teaching experience and the use of modeling and hours of teaching and the use of modeling. *Correlation is significant at the 0.05 level and **Correlation is significant at the 0.01 level.

MANOVAs. To further explore the effect of the independent variables (grade levels, type of classroom teacher characteristics and demographics) on instructional practices, several multivariate analyses of variance (MANOVA) were conducted. Table 7 below presents the results and indicates that there was a significant difference (p. <. 01) between grade levels on all types of modeling instruction, except for "Demonstrating Modeling."

Table 7

MANOVA: Grade Level by Model Inclusion and Instruction

Concept	Type III Sum of Squares	df	Mean Square	F	Sig.
Use Existing Models	8.292[a]	1	8.292	8.569	0.004
Create Physical Model	11.120[b]	1	11.12	12.492	0.000
Develop Conceptual Model	11.615[c]	1	11.615	11.947	0.001
Represent Relevant Components	20.676[d]	1	20.676	21.454	0.000
Discuss Scientific Models	26.044[e]	1	26.044	26.253	0.000
Use Simulated Models	15.511[f]	1	15.511	13.132	0.000
Revise Models	18.432[g]	1	18.432	17.305	0.000
Identify Strengths/ Limitations	21.496[h]	1	21.496	19.789	0.000
Write About Observed Models	5.467[i]	1	5.467	5.964	0.015
Demonstrate Modeling	.525[k]	1	0.525	0.55	0.459
Modeling to Engage Students	7.092[l]	1	7.092	6.468	0.012
Revise Own and Others Models	7.813[m]	1	7.813	6.787	0.010

Note. There is significant difference between grade levels on modeling instruction at the $p < .01$ except Demonstrating Modeling is not statistically significant. Mean and standard deviation are captured in Appendix J.

Table 8

MANOVA: Self-Contained Classes by Model Inclusion and Instruction

Concept	Type III Sum of Squares	df	Mean Square	F	Sig.
Use Existing Models	7.150	2	3.575	3.665	.027
Create Physical Model	10.005	2	5.002	5.572	.004
Develop Conceptual Model	8.827	2	4.414	4.475	.012
Represent Relevant Components	7.903	2	3.951	3.892	.022
Discuss Scientific Models	9.333	2	4.667	4.408	.013
Use Simulated Models	7.933	2	3.967	3.267	.040
Revise Models	7.146	2	3.573	3.214	.042
Identify Strengths/ Limitations	7.255	2	3.628	3.171	.044
Write About Observed Models	5.658	2	2.829	3.077	.048
Demonstrate Modeling	3.718	2	1.859	1.964	.142
Modeling to Engage Students	6.671	2	3.336	3.027	.050
Revise Own and Others Models	4.182	2	2.091	1.789	.169

Note. There is a significant difference between self-contained classrooms on modeling instruction at the p. <.05, and p. < .01 levels. Mean and standard deviation are captured in Appendix K.

Table 8 presents the results of the MANOVAs that examined type of classroom environment and reported used of modeling instruction. A significant difference was observed between self-contained classrooms as opposed to departmentalized classrooms in reported use of modeling instruction. Eight of the 12 modeling facets were reported to be used more frequently by teachers in departmentalized classes than those in self-contained classes ($p. <.05$ level). Four of the twelve modeling facets were significant at the $p. < .01$ level, indicating that teachers in departmentalized classes report using the following practices more often than those in self-contained classes: creating a physical model, developing a conceptual modeling, and discussing how scientific models and explanations are based on existing models. Demonstrating what modeling looks like and revision of models showed no statistical differences.

Table 9

MANOVA: Science Coordinator & Teacher Impact On Modeling Instruction

Concept	Type III Sum of Squares	df	Mean Square	F	Sig.
Use Existing Models	9.052	2	4.526	4.674	.010
Create Physical Model	9.374	2	4.687	5.207	.006
Develop Conceptual Model	7.727	2	3.863	3.901	.021
Represent Relevant Components	9.475	2	4.738	4.693	.010
Discuss Scientific Models	6.145	2	3.072	2.870	.058
Use Simulated Models	17.013	2	8.506	7.209	.001
Revise Models	17.257	2	8.629	8.037	.000
Identify Strengths/ Limitations	12.399	2	6.200	5.513	.005
Write About Observed Models	6.195	2	3.098	3.376	.036
Demonstrate Modeling	.806	2	.403	.421	.657
Modeling to Engage Students	1.501	2	.750	.669	.513
Revise Own and Others Models	6.160	2	3.080	2.651	.072

Note. A statistical difference obtained at the p. <.05 level for Writing About Models and Developing Conceptual Models. Mean and standard deviation are captured in Appendix L.

Table 9 indicates the results of the MANOVA for use of specific modeling practices between science coordinators and teachers. Seven were significant at the p.<.01 level. These include: using existing models, creating physical models, using simulation models, revising models, and identify strengths and limitations of models.

Tukey HSD (honest significance difference) post hoc exploratory tests were conducted to determine if there significant differences between science coordinators' and teachers' use of modeling strategies, since the science coordinators were exposed to more training sessions than teachers. This test showed that science coordinators demonstrated modeling significantly more so than classroom teachers in each significant finding.

There was a small and minimally significant (p. <.05) finding for school type (title 1 and non-title 1) and frequency of use of the modeling instruction practices. This is represented by the graph below in Figure 9.

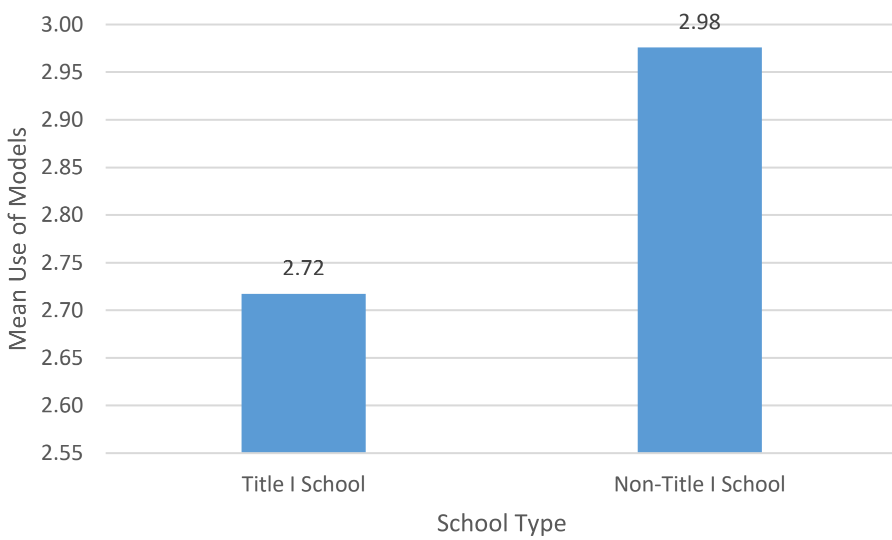


Figure 9. MANOVA comparison between Title I school type and mean Instructional Use of Creating Physical Models. Significant at the F(1, 267)=4.88, p. <.05.

Discussion

This exploratory study focused on grades 1-5 teachers' self-reported development and use of models, one of 8 SEPs, in science instruction that were observed for the three research questions on teachers' use of modeling strategies, barriers to teachers' use of modeling strategies and relationships and differences between grade level, school type and teacher role on the use of modeling strategies in their science instruction. Several conclusions can be tentatively drawn. First, there is a promising but low report of the frequency of the use of modeling instruction for most or all 12 modeling facets studied. Second, there were several barriers that teachers reported to their use of modeling strategies in science instruction. Third, several factors, including grade level, teacher role classroom setting were shown to relate to the frequency of use of modeling strategies in science instruction.

Frequency of Use of Modeling Instruction

The findings from Table 4 and research question 1 showed an average of 34% of grades 1-5 teachers reported that they never or rarely used one of the twelve modeling practices, and 33% of the teachers reported that they sometimes use one of the twelve modeling practices as part of their science instruction. These findings are consistent with the current research showing that students' modeling opportunities are rare in elementary classrooms (Berland et al., 2016; Windschitl, Thompson, & Braaten, 2008; Forbes, Vo, Zangori, & Schwartz, 2015; Schwartz, Passmore, & Reiser, 2017).

Barriers to Teachers' Ability to Support Students' Construction of Models

The findings for research question 2 showed an average of 44% of grades 1-5 teachers reported that each of the seven barriers were rated as somewhat = 4 or a major barrier = 5. Among those barriers that were considered to be the most major were: limited instructional time to teach science (mean = 3.67), and limited materials, including digital devices and science equipment (mean = 3.52). This is consistent with current research that says that there are several inequities for resources in current elementary science instruction across the country (Banilower et al., 2013; NGSS Lead States, 2013; Wilson, 2013; NRC, 2012; Haag & Megowan, 2015; Reiser, 2013).

Limited instructional time to teach science ranked as the highest ranked barrier to teachers' ability to support students' construction of models (mean = 3.67). Instructional time allocated to science in grades 1-5 is less than half that for mathematics and RELA. Twenty-three percent of the grade 1-5 teachers report that they spend four or more hours per week teaching science, compared to 64 % for mathematics and 52% for RELA, respectively. Thirty-eight percent of grades 1-5 teachers reported teaching science between 0-2 hours per week. This finding of limited science instructional time is also consistent with current research that says adequate instructional time for elementary science instruction needs to be provided in order to teach the new NGSS (Banilower et al., 2013; Trygstad et al., 2013; NGSS Lead States, 2013; Nollmeyer, 2013; Bybee, 2013; Hayes, 2014).

District Q's K-5 Science curriculum documents (District Q, Science Office, 2017) suggest the following allotted time instructional guidelines: Grades K-2 are to receive 45 uninterrupted minutes of daily science instruction with the exception of one day of the week where students are to receive 30 minutes of science and 15 minutes of health instruction. Elementary grades 3-5 are to receive 60 uninterrupted minutes of daily science instruction except the one day when students are to receive a 30-minute block of science and 30 minute block of health. This means that K-2, teachers should be teaching a minimum of 3.5 hours of science per week and grades

3-5 teachers should be teaching a minimum of 4.5 hours of science per week. However, from the results of this study, only 4 % of grades 1-2 teachers and 19% of grades 3-5 teachers reported teaching science the allotted instructional time. Given the research that has shown that instructional time is highly correlated with student achievement (Gettinger, 1985; Dobbie & Fryer, 2011) and increased test scores (Blank, 2013; Judson, 2013), the findings of this study suggest that insufficient instructional time in science may be contributing to the low student achievement on past state science assessments. Adequate instructional time will become even more important with the implementation of NGSS and the new more rigorous, PARCC like 5th grade science state assessments (MISA), that require students to interact with interactive simulations and models to explain phenomena in various technology enhanced environments. This expectation will necessitate the need for students to experience this demand of NGSS, in a daily classroom culture, hence adequate allotted instructional time needs to be reallocated for students to master these practices and be successful on these rigorous assessments.

A school culture that focuses only on Common Core mathematics and RELA was ranked the 3rd highest barrier (mean = 3.27), and teacher effects were ranked the 4th, 5th and 6th barriers collectively for adequate professional learning opportunities to help them understand NGSS and the SEPs (mean = 3.00), their lack of understanding the expectations of NGSS (mean = 2.89) and their level of understanding of the district's science instructional resources (mean = 2.81). An average of 38% of grade 1-5 teachers reported that they lacked of adequate professional learning opportunities to help them understand NGSS and its SEPs. This average is higher (mean = 3.21) for grade 1-2 teachers. Several researchers assert that for any successful implementation of NGSS, meaningful, targeted, and differentiated professional development strategies must be provided to will all teachers' needs (Reiser, 2013; NRC 2012; Nollmeyer, 2014; Wilson, 2013; Bybee, 2013). Thus, this finding suggests a need for District Q to examine the extent and types of professional learning opportunities available to its elementary level teachers.

Twenty-seven percent (mean = 2.66) of grade 1-5 teachers ranked inadequate administrator support as the 7^{th} barrier to their use of models in their science instruction. Several studies have identified building administrators support or lack of support to elementary science instruction as a significant variable impacting the successful implementation of new standards such as NGSS (Banilower, 2013; NGSS Lead States 2013; Hayes, 2014; Bybee, 2013; Brogdon, 2015). Hence, the findings from this study suggest that more administrators' support will be needed for their grade 1-5 teachers in order to successfully implement NGSS and support their teachers' ability to support students' construction of models in their classrooms. This mid-Atlantic state and District Q have recently adopted the 2015 Professional Standards for Educational Leaders (PSEL), several of these standards address the need for administrators to be effective instructional leaders by supporting the implementation of standards, curriculum, instruction, assessment, equity and access to resources (MSDE, 2017). Additionally, Walters et al. (2013) found from the 21 leadership responsibilities that positively correlate with student achievement, several are grounded in principals' involvement with curriculum, instruction, and assessment, knowledge of curriculum, instruction and assessment, being a change agent and providing adequate resources to teachers.

According to the results of the MANOVA (Table 7), teachers in grades 3-5 were using more modeling instruction than their grades 1-2 colleagues. This may be attributed to the fact that 48% of the grade 1-2 teachers reported that they need more training to help with their understanding of the shifts and demands of NGSS. Teachers in a departmentalized classroom setting also provided significantly more modeling instruction to their students compared to self-contained classrooms. This could have been attributed to the fact that schools that are departmentalized have grades 1-2 teach all content subjects to include mathematics, RELA, science, social studies, health and other content, whereas in grades 3-5 classes, science instruction is conducted by science content specialists and secondly more hours of science are taught in grades 3-5 as was discussed earlier. When compared to their non-science coordinator peers, teachers who were also science coordinators provided more modeling instruction around existing models, creating physical models using simulation models, revising models and identifying the strengths and limitations of models. This finding could be as a result of the science coordinators receiving more training than their counterparts. For example, quarterly targeted professional development opportunities are offered to the science coordinators by District Q's science office staff. With limited funding, these professional learning opportunities are targeted to the science coordinators with the expectation that when they return to their respective schools, they share the received information and practices with their teachers and administrators. Non-Title I schools also exhibited a significant difference in providing more modeling instruction (mean = 2.98) when compared to Title I schools (mean = 2.72). This finding suggests that socio-economic factors may also be significant variables affecting teachers' their ability to support students' construction of models in their classrooms. This finding is huge, considering that 46% of District Q's elementary student population is enrolled in Title I schools (MSDE Reportcard, 2017). Second, the 5th grade MSA average proficiency levels for FY11-FY15 was 14% lower for students of Title I schools when compared to their non-Title I counterparts (MSDE Reportcard, 2017).

Summary Recommendations and Limitations

This study contributed to my understanding of the vision and demands of NGSS. In this study, it was also revealed that a few key factors such as adequate instructional time, access to digital devices for all students, and relevant professional development opportunities will need to be addressed by District Q as it moves forward with its efforts to implement NGSS and improve student achievement.

Limitations of the study. There were several limitations to this study. The first and probably most important is the limited response rate. A higher percent of survey completion was expected. The survey was distributed via email and there was a reminder email as well as incentives for completion, all of which follow procedures for survey implementation (Kelley et al., 2003). In addition, an email was sent to principals of all elementary schools asking them to encourage their teachers' participation. The low response rate might be due to incorrect emails, emails that went to the teachers' spam or trash or was blocked by the district's firewall. Also, there is no way to know whether principals encouraged their teachers' participation.

Another factor was the timing of the survey. The survey was open during weeks' three and four of the new school year and teachers may have had other priorities. The response rate does impact generalizability of the findings.

An additional limitation is the use of a survey tool as the only instrument to obtain teachers' self-reported instructional practices around the SEPs and models. Hence, it has inherent issues of validity, as teachers may over or underrate items depending on their perception of their practice and desires to please the researcher (Garet et al., 2001). Responses may have also been influenced by the degree to which the teachers understood the construct being measured. For example, the item on demonstrating modeling as was discussed earlier, may have been misinterpreted to mean demonstrating what the product looks like, instead of creating and sustaining a modeling culture that involves all the modeling facets. Additionally, self-contained teachers may not have interpreted some answers (never to daily) in the same way compared departmentalized setting (science specialists). Hence, triangulating this survey results with classroom observations and teacher and principal interviews, would have addressed some of the assumed inherent validity concerns (Hayes, 2014).

Implications for District Q. The purpose of this study was to explore and document the extent to which grade 1-5 teachers support the use of models for the purpose of constructing explanations. Additionally, what barriers, relationships and differences exist between teacher characteristics and demographics with respect to teachers' use of models in District Q. Below are some suggestions to consider as the district continues to strive to increase student achievement for all K-12 learners, through various initiatives to include the implementation of NGSS:

1. Reallocation and leveraging of resources to support NGSS instruction: As discussed earlier, the new 5th grade NGSS state assessment (MISA) will be 100% online, interactive, and similar to PARCC assessments. All students are expected to demonstrate mastery of phenomena for over 11 integrated Performance Expectations for life science, physical science, earth and space science and engineering applications. Students are expected to use the SEPs, to address phenomena-based questions through simulations, evidence-based explanations and argumentations. Modeling is also at the core of this assessment. Daily access to science materials, equipment and digital devices would have a greater impact on increased student achievement on these assessments. Through continued advocacy for relevant policy changes, at the time of completion of this dissertation, the researcher is proud to say that the leadership of District Q has stepped up to the challenges and demands of NGSS implementation and have purchased science materials' kits that are aligned to the K-5 curriculum in support of grades K-5 science instruction. The researcher commends the leadership of District Q for this major support. However, several aspects of reallocating resources to support NGSS implementation still need to be addressed. These include daily access to the use digital devices for all students. As is seen from the analysis of this study, this is the number one barrier to teachers' use of modeling in their classrooms, especially for elementary students who need to interact with simulations to address misconceptions of phenomena, and make sense of the unobservable world through the development of models as they construct evidence-based explanations and argumentations. Additionally, for teachers to support a modeling culture of their students in science instruction, adequate instructional time

will be needed for students to practice and master the various facets of modeling instruction, through various iterative modeling protocols. This shift will require that schools and administrators leverage their use of technology to support grades 1-5 implementation of NGSS.

2. More support for Professional Learning Opportunities for Teachers and Administrators:

Currently, due to limited financial and human capital in the District Q's Science Office, the needed, SCK and PCK targeted professional learning opportunities offered around the SEPs to elementary teachers is limited to a few sessions per quarter as opposed to a series of continuous sessions around the SEPs, to include modeling. This is crucial for the successful implementation of NGSS, especially the need for face-to-face embedded professional learning opportunities to support the demands of 3-D teaching through the SEPs to include developing a modeling culture. Currently, there are four staff members in District Q's K-12 Science office. With the demands for more systemic and school-based professional learning opportunities around NGSS and the SEPS, District Q's leadership could support this need by providing additional staff and funding. Additionally, there is a huge implication for collaborations between the district and local universities and STEM organizations in support of needed large-scale SCK and PCK professional learning opportunities on NGSS 3-D instruction for elementary teachers.

3. Leverage and reallocate more instructional time for science instruction:

NGSS requires that adequate time be provided for all students to do science through the SEPs, particularly all the facets of modeling, as is described in this research, however, this adequate time is not provided. Currently, there is no structured administrative procedure or accountability system in place for the instructional time allotments of the 4 core content areas. Suggested guidelines for allotted instructional times were developed over a decade ago, prior to MISA and PARCC and captured in current curriculum documents. In an effort to support the district's initiative of increased academic achievement for all students on high stakes state assessments such as MISA and PARCC, District Q's leadership could revisit this issue and develop an equitable instructional time allotment accountability system for all schools to follow.

4. Curriculum Reform: Common Core Math & RELA integration with NGSS:

From Figure 4 (Cheuk, 2012, relations and convergences in literacy, math and the SEPs), there are significant synergies and overlaps of the NGSS and CCSS practices. This allows for rich opportunities of cross-subject integration, where the SEPs, literacy strategies, reading, writing, speaking and listening are commonalities in all core curricula. In the current climate where the availability of instructional time is of essence, District Q could consider a more integrated, symbiotic approach to the K-5 core curricula as a strategy for a shared vision of NGSS and CCSS support. For example, once the culture of the development and use of models is established in elementary science instruction, concurrent applications and integration could occur with the mathematics practice of modeling with mathematics. This modeling foundation will allow for greater synergy in secondary grades between science and mathematics.

Additionally, District Q could identify a task force of cross content experts to develop and integrate a K-5 curriculum that supports all standards and all students, this innovation can be a major flattening agent that could address the limitations of resources and instructional time.

5. Principals' as Instructional Leaders: Support for all content and all standards:

With District Q's systemic initiative of developing a high performing workforce in order to support high academic achievement for all students, principals' support as an instructional leader in their buildings would be a crucial factor in the successful implementation of the demands and vision of NGSS. District Q's leadership could continue to support systemic principals' participation in NGSS professional learning opportunities, so that they can better support their teachers.

Recommendations for future research. This exploratory investigation provides a good snapshot of the status of grades 1-5 teachers' use of the SEPs, other instructional strategies, barriers, and relationships and differences between teacher characteristics and demographics on their ability to support their students' development and us of models for the purpose of constructing explanations. Research on the use of SEPs to drive 3-D instruction of NGSS in elementary science instruction is still in its infancy, since the implementation of NGSS of the 18 adopted states is fairly new. Below is suggested research to help to add to the body of literature on this topic.

Recommendation 1

The current study involved 269 participants from a large potential sample size of 1,200 and secondly, the teachers self-reported their responses. The researcher would recommend that a similar study be conducted for a longer period of time and a larger sample size, coupled with triangulation strategies such as teacher observations and principal interviews, so that inherent validity and generalizations are addressed.

Recommendation 2

Since NGSS strives for accessibility and equitable learning opportunities for all students and District Q's student population is very diverse, there was a significant difference between Title I and non-Title I schools in this research, the researcher recommends that a similar study be conducted specifically for Title I and non-Title I schools.

Recommendation 3

A similar recommendation can be made for grades 1-5 teachers in District Q's schools with a large population various subgroups such as English Language Learners, students with disabilities, gifted and talented, and Special Education.

Recommendation 4

Since District Q has a NGSS aligned Curriculum with science materials, the researcher would recommend a study be conducted to explore the effects of these resources on student performance on the new 5th grade state science assessment (MISA).

Summary

In this section, the researcher presented an overview of the findings and conclusions of this research. Additionally, recommendations for District Q, limitations to the research, and recommendations for future research were presented. Of major significance of the findings of this study is the need for access and equitable distribution of resources to support the vision and demands of implementing NGSS through the SEPs, specifically that of developing a modeling culture in all elementary science classrooms. Fulfilling this need would be critical to increased student achievement, especially in underrepresented non-dominant groups (Appendix D, NGSS Lead States, 2013). As is seen in Figure 4, engaging in curriculum integration that makes use of the interconnectedness and commonalities of NGSS, mathematics and RELA practices (including literacy connections), could also be a future practice that would lead to increased student achievement on local, state, and national assessments in the core content areas.

Appendices

Appendix A

Summary of the current State and Local Initiatives in support of teachers' SCK and PCK on the Implementation of NGSS in District Q.

Programs	Description	Expected Outcomes and Implications for District Q
MSDE-NGSS Timeline Implementation	All 24 LEAs are expected to fully implement K-12 NGSS by 2018.	Human capital challenges will limit the fidelity of implementation.
MSDE – New NGSS-MISA Timeline and Prototypes	5^{th} and 8^{th} grade MISA piloted in FY17 and FY18 and fully implemented with accountability in FY19.	Teachers and administrators trained on these new MISA Items. Science office staff will have to develop and test sample MISA Items.
MSDE-NGSS Webinars	A series of webinars on the three dimensions of NGSS, lesson plans and assessments conducted my master teachers for all teachers in the state.	All K-12 Science teachers participate in the webinars with the expectation to increase their SCK and PCK on NGSS implementation.
MSDE Science Supervisors' Briefings on NGSS	All Science supervisors from the 24 LEAs in the state participate in quarterly NGSS Briefings and collaborate on a shared implementation plan for their LEAs.	Based on the information from these briefings, District Q Science supervisor and staff designed and implemented 3-dimensional NGSS professional learning experiences for K-12 Science teachers.
District Q K-12 Literacy Plan	District Q developed their own definition for literacy and instituted a K-12 Literacy Plan in FY16. In this plan, all content areas infuse and support speaking, listening and reasoning in K-5 and the writing task in grades 6-12.	Through the K-5 Literacy plan and tool kit, several overlapping SEPs are addressed in support of the two interdisciplinary goals: Reading and writing across all content areas and Reasoning in all content areas.

MSDE's COMAR Approval of an Instructional Leader, STEM, PreK-6 Certificate	This STEM certification is open to all K-8 science and mathematics teachers.	Several District Q's K-6 science teachers participate in various STEM certificate programs in collaboration with District Q's Office of Talent Development and various university partners in the state.
District Q – UMBC STEM Master of Arts in Education (MAE) Certificate Cohort Program	This cohort began in Spring 2015. It is a three-year program. Teachers gain the STEM Instructional Leader endorsement on their state's teaching certificate Nineteen total teachers are in the 1st cohort. There are 7 teachers from District Q of which 5 are K-5 teachers.	The 12 course requirements for this STEM Certification were designed to increase the SCK and PCK capacities of the participating teachers in the implementation of NGSS. Six of these courses are considered content courses (UMBC, 2016) the other six education pedagogy and leadership courses (UMBC, 2016). It is expected that these teachers will serve in STEM leadership roles in their schools and the district.
District Q – UMCP STEM Administration I Cohort Program	Twelve K-8 District Q teachers are in this 15-member 1st cohort. This 12-month program started in September 2015. The Program content consists of five 3-credit courses and three 1-credit internships. The courses are designed to cover the content focus of the District Q Leadership Standards, the 2005 Maryland Instructional Leadership Framework, the 2014 Interstate School Leaders Licensure Consortium (ISLLK) Educational Leadership Policy Standards, and the Educational Leadership Constituent Council (ELCC) 2011	Current research (Bybee, 2013; NRC, 2012; NSTA, 2013; NARST, 2013, 2014; NGSS Lead States 2013) suggest that district- and school-based administrators' leadership and support will play a crucial role in the success of NGSS implementation in any district. It is the expectation that upon successful completion of the STEM Administrator 1 certificate, cohort 1 will be a model for administrators in the support of a successful NGSS implementation in the district. It is also expected that more science teachers

	Standards for Building-Level Leader Preparation. MSDE requires applicants for Administrator 1 certification to demonstrate proficiency on ELCC.	in the district participate in such programs.
District Q – MSU Administrator Doctoral STEM Program	A Memorandum of Understanding was signed on June 26, 2015, between Morgan State University (MSU), on behalf of its School of Education and Urban Studies, and District Q) Board of Education to develop and provide a doctoral program for selected leaders of the Office of the Chief Executive Officer. The Ed.D. programs in both Mathematics and Science Education are designed to help in-service teachers and educational leaders: • Prepare for and successfully acquire positions in mathematics and science education school and district leadership, higher education, and non-profit organizations • Address critical problems and issues facing the mathematics and science education of urban learners • Engage in rigorous and cutting edge coursework in education foundations, research, mathematics and science content, and mathematics and science curriculum, instruction and assessment	This three-year cohort-based program will consist of 54 post-Masters credits. For students who have not completed graduate level Mathematics or Science Content courses, the program will 66 credits (District Q, OTD Office, 2016). The mission of the Morgan State doctoral program is to improve the quality of mathematics and science education, to spur math and science achievement, and increase awareness of math and science oriented careers, especially in urban schools serving minority populations. The Expected outcomes include: • Train highly qualified teachers, supervisors, administrators, and curriculum specialists • Complete required courses needed for Maryland State Administration Certification • Provide instructors with expertise in both research and practice, particularly mathematics and science education in urban context and with

	A cohort of 12 district leaders and teachers begin their program of study, fall 2016.	urban learners
District Q Science Office Quarterly Department Chairs' Workshops on NGSS Implementation	With limited funding, for the past 3 years, District Q K-12 Science Office has been developing and presenting best practices on the three dimensions of NGSS Implementation to K-12 Science leaders in the district. These include the purchase of several NGSS publications to support the modeling of what the SEPs, DCIs, and CCCs look like in a NGSS classroom, utilizing experts such as Rodger Bybee and developing 3-dimensional lessons.	The challenge with this model is that the best practices or information shared, reach the classroom teacher at all times, hence, NGSS SCK and PCK that is most needed by our K-5 teachers are lacking. Consistent with current research, adequate senior leadership support and funding, is necessary to support the District Q Science Office so that the K-5 teachers receive direct professional learning opportunities on NGSS Implementation in the district.
District Q Science Office K-12 Curriculum Redesign	K-12 NGSS Resources will be adopted and Curricula designed, developed and implemented in FY17-FY18. MISA items will be piloted.	Approximately 2,000 K-5 teachers will be trained on the new resources to support SCK and PCK on NGSS Implementation.
District Q Science Office K-8 Discovery Education *Science Techbook* Collaboration	District Q Science Office is collaborating with Discovery Education *Science Techbook* to align and offer Professional Learning experiences in order to increase teachers' SCK and PCK on NGSS implementation.	Teachers will be exposed to an aligned NGSS digital curriculum in support of increased student achievement.

Appendix B – Survey of Teacher Practice: Next Generation of Science Standards

Start of Block: Informed Consent & Demographics

Q1 I have read, and understood the above consent form and of my own free will, plan to:

- ○ voluntarily participate in this survey
- ○ not participate in this survey

Q2 Which school type best describes where you teach?

- ○ Title I School
- ○ Non-Title I School

Q3 What grade level do you teach?

- ○ Grades 1-2
- ○ Grades 3-5

Q4 Overall years of teaching experience

- ○ 0- 5 years
- ○ 6-10 years
- ○ 11-15 years
- ○ 16-21 years
- ○ > 21years

Q5 Which of the following best describes how science is taught at your school?

○ self-contained classes teaching all core subjects (math, science, reading English language, & social studies)

○ self-contained classes with grade 3-5 students receiving science instruction from a science specialist (departmentalized)

○ self-contained classes pulled out for enrichment in science

Q6 Do you hold any of these additional positions in your school?

○ Science Elementary Coordinator (EC)

○ Professional Development Lead Teacher

○ I am a classroom teacher

Q7 Select the statement that best describes the science course/courses you have completed in college

▼ All four domains – life science, earth and space science, physical science and engineering ...

None of the above

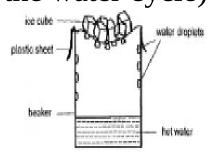
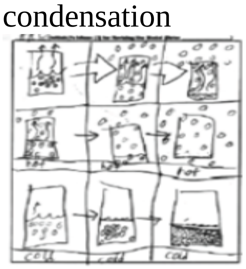
Q8 During a typical week, about how many hours do you teach the following content?

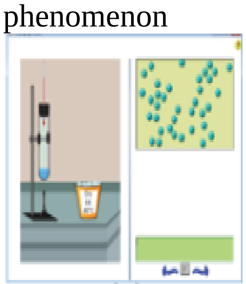
	1 hour or less	1-2 hours	2-3 hours	3-4 hours	More than 4 hours
Science	○	○	○	○	○
Common Core Mathematics	○	○	○	○	○
Common Core RELA	○	○	○	○	○
Social Studies	○	○	○	○	○

Start of Block: Instructional approaches on the development and use of models

Q 9 The following questions are based on strategies used to support the development and use of models. Models can be seen as traditional or conceptual representations that either explain or predict a scientific process or phenomenon. For example, traditional models include things like textbook models such as the solar system. Student generated models to explain phenomena such as the water cycle's various components (i.e., evaporation, condensation, precipitation, and runoff) are examples of conceptual models. In the science classroom, students may use existing models or may develop their own models to explain phenomenon.

How often do your students do each of the following in your science classes?

	Never	Rarely (a few times a year)	Sometimes (once or twice a month)	Often once or twice a week)	Daily or almost daily
Use existing models to construct explanations of phenomenon					
Create a physical model of a scientific phenomenon (like creating a representation of the water cycle) 					
Develop a conceptual model based on data or observations (generated by students-model is not provided by textbook or teacher) for example a student generated model of evaporation and condensation 					
Represent relevant components of a phenomenon when developing					

models, for example the relevant components of the water cycle 					
Discuss how scientific models and explanations are based on existing evidence					
Use simulation models (such as the Concord Consortium or PhET Simulations) to generate evidence to support a scientific explanation of a phenomenon 					
Revise scientific models based on additional evidence					
Identify the strengths and limitations of a scientific model					

Start of Block: Measuring Instructional Practices to support the shifts demands of teaching NGSS

Q10 The following questions address instructional approaches used to teach science. How often do you do each of the following in your science classroom?

	Never	Rarely (a few times a year)	Sometimes (once or twice a month)	Often (once or twice a week)	Daily or almost daily
Have students generate or identify questions or predictions to explore real world phenomena*	○	○	○	○	○
Have students design or implement their own investigations	○	○	○	○	○
Have students write about what was observed and develop models to explain why it happens	○	○	○	○	○
Provide direct instruction to explain science concepts	○	○	○	○	○
Demonstrate an experiment and have students watch	○	○	○	○	○
Use worksheets to reinforce practices or content	○	○	○	○	○
Define vocabulary	○	○	○	○	○

words before a lesson is taught					
Talk with students about things they do at home that are similar to what is done in science classes, e.g., measuring, boiling water)	◯	◯	◯	◯	◯
Have students work in small groups	◯	◯	◯	◯	◯
Encourage students to explain science concepts to one another	◯	◯	◯	◯	◯
Use the district's curriculum to teach NGSS lessons	◯	◯	◯	◯	◯
Use the Science and Engineering Practices (SEPs) to teach science	◯	◯	◯	◯	◯
Use the claim, evidence, and reasoning model to generate scientific explanations	◯	◯	◯	◯	◯
Demonstrate what	◯	◯	◯	◯	◯

modeling looks like in my classroom					
Use modeling to engage students in the other Science and Engineering Practices (SEPs) such as constructing explanations or argumentation	○	○	○	○	○
Have students revise their own and others' models in an effort to develop consensus models?	○	○	○	○	○

Start of Block: Barriers on the use of modeling in my classroom

Q11 Rate these statements as follows: not a barrier, mostly not a barrier, neutral, somewhat a barrier and, major barrier to developing a modeling culture in my school and classroom

	Not a Barrier	Mostly Not a Barrier	Neutral	Somewhat a Barrier	Major Barrier
My school culture only focuses on Common Core Mathematics and RELA	○	○	○	○	○
Limited instructional time	○	○	○	○	○
Limited instructional materials to include digital devices and science equipment	○	○	○	○	○
My level of understanding of the expectations of NGSS	○	○	○	○	○
My level of understanding of the district's science instructional resources (to include curriculum)	○	○	○	○	○
Inadequate Professional Development opportunities to help me understand the NGSS Science and Engineering Practices	○	○	○	○	○

Inadequate administrator support for science instruction	○	○	○	○	○

Start of Block: Incentive Option

Q12 Do you want to be entered in a raffle for a prize?

○ Yes

○ No

Appendix C

Email to Principals

Re: Survey of Teacher Practices: The Next Generation of Science Standards (NGSS) in Grade 1-5
From: Godfrey Rangasammy (grangasa@umd.edu)
To: Principals' Email Address

Greetings ES & K-8 Principal Colleagues,

As you may be aware, I am in the process of completing my doctoral studies at the University of Maryland. As a final component of my program, I must write a dissertation, which is a research study. The focus of my dissertation research is to examine teacher use of the Science and Engineering Practices in grades 1 through 5. To research this topic, we are asking teachers who teach grades 1 through 5 in your building to take a short survey, which will take approximately 15 minutes.

This email is being sent to you for your help. Please forward the message & survey link below to ALL of your grade 1-5 teachers and encourage them to complete the survey no later than September 29, 2017.

Teachers, Click this link to take the teacher survey:

https://umdsurvey.umd.edu/jfe/form/SV_cvGhKXf4YTm8S9L

Sincerely,

Godfrey Rangasammy
grangasa@umd.edu
301-442-1080

Appendix D – Cover Letter

I am a doctoral candidate at the University of Maryland. I am currently in the research phase of my study. My focus will be on the use of the Science and Engineering Practices by grade 1-5 teachers in the district. This investigation will examine how and to what extent the district's grade 1-5 science teachers are engaging students in the use of Science and Engineering Practices, specifically the development and use of models and development of models in their science instruction. This will require that I survey all grade 1-5 teachers in the district.

The survey will be quick, requiring less than 15 minutes of your time to complete. The survey will ask questions on demographics, on the use of the Science and Engineering Practices of the NGSS, use of modeling in grade 1-5 classrooms, and barriers to the use of modeling in science instruction. This survey will be available for two weeks with the expectation of obtaining at least 85% participation of the staff in all grade 1-5 classrooms in the district.

The district's Research and Evaluation Office and the University of Maryland's Research Office have granted my approval to conduct this study. If you have any questions about this survey before you start or while taking it, please contact Godfrey Rangasammy (grangasa@umd.edu) to discuss your question. I am willing to meet with you to discuss the survey in depth if needed.

Appendix E – Email to Participants

Re: Survey of Teacher Practices: The Next Generation of Science Standards (NGSS) in Grade 1-5
From: Godfrey Rangasammy (grangasa@umd.edu)
To: Participant Email Address

Dear Participant,

I am inviting you to participate in a study that will explore how and to what extent the district's grade 1-5 teachers support students on the use the Science and Engineering Practices, specifically, the use and development of models for the purpose of constructing explanations in science instruction. This study is being conducted as part of my dissertation research at the University of Maryland, under the direction of Dr. Margaret J. McLaughlin. Your participation in this survey could offer a potential benefit to the district in determining professional development needs of teachers, as the NGSS is implemented.

This survey should not take longer than 15 minutes. It is anonymous and your participation is voluntary. Upon completion, you will be asked if you would like to participate in a raffle for a chance to win one of fifty $10 electronic Amazon.com gift cards. If you chose yes, you will be directed to a secondary survey link that asks for your email address. Your responses to the first survey are not connected to the secondary survey, hence your responses will still remain anonymous.

Please use this link to access the survey:

This link is uniquely tied to this survey and your email address. Please do not share nor forward this message.

If this link does not work, please copy and paste the link into your web browser.

Thanking you in advance for completing this survey.

Godfrey Rangasammy
grangasa@umd.edu
301-442-1080

Appendix F – Informed Consent Template

Project Title	Investigating Teachers' Reported Use of Science & Engineering Practices (SEPs) in Elementary Instruction.
Purpose of the Study	Godfrey Rangasammy at the University of Maryland, College Park, is conducting this research. We are inviting you to participate in this research project because this study focuses on grade 1-5 teachers and you are a grade 1-5 teacher in the district. This study will examine how and to what extent, the district's grade 1-5 teachers support students on the use of models for the purpose of constructing explanations.
Procedures	In order to investigate the use of the SEPs, specifically practice 2, developing and using models by grade 1-5 teachers in the district, a web-based survey using the Qualtrics software tool will be used to address the needs and research questions of this study. This survey will be administered to all of the district's grade 1-5 teachers. The email addresses of all grades 1-5 teachers in all elementary and K-8 schools will be obtained from the district's website at http://www1.pgcps.org/. This survey will be comprised of four sections. The first section of the survey will be asking general demographics questions, followed by three other sections that specifically ask relevant questions pertaining to topics on the three research questions' on the use of the science and engineering practices in grade 1-5 science teachers' classrooms in the district The survey will take approximately 15 minutes to complete. Two options are considered for the distribution of the survey to the grade 1-5 teachers. The first is to email the consent form with the survey link to all the grade 1-5 teachers. The second is to use a flyer with the consent form and survey link and have the principals distribute to their grade 1-5 teachers.
Potential Risks and Discomforts	There are no known risks associated with participating with this research project.
Potential Benefits	There are no direct benefits for you. However, as a whole system, it is hoped that the research findings from this study will inform the district, state and country on the state of the grade 1-5 teachers' use of Science and Engineering Practices (SEPs), specifically, the development and use of models, of the Next Generation of Science Standards (NGSS) in grade 1-5 science classrooms, hence, offering insights for data-driven professional learning opportunities for central office and building administrators, to support the PCK and

	SCK for our teachers.
Confidentiality	All data obtained from you will be kept confidential and will be reported in an aggregate format. Additionally, storing the collected data in a HIPPA-compliant, secured database on a password-protected computer, will minimize any potential loss of confidentiality. If we write a report or article about this research project, your identity will be protected to the maximum extent possible. Your information may be shared with representatives of the University of Maryland, College Park or governmental authorities if you or someone else is in danger or if we are required to do so by law.
Incentive	For incentive purposes, in order to maintain the anonymity of the schools and participants' data, a URL will be created at the end of the first anonymous survey in Qualtrics. This URL will redirect you to a secondary survey, where additional information such as email address can be obtained. An electronic Amazon.com gift card can then be emailed to the first 50 participants who have completed the survey. The email addresses collected in the secondary survey would not be associated with the responses in the first survey, hence maintaining anonymity.
Right to Withdraw and Questions	Your participation in this research is completely voluntary. You may choose not to take part at all. If you decide to participate in this research, you may stop participating at any time. If you decide not to participate in this study or if you stop participating at any time, you will not be penalized or lose any benefits to which you otherwise qualify. Your decision to participate or not participate will have no effect on your employment status with the district. If you decide to stop taking part in the study, if you have questions, concerns, or complaints, or if you need to report an injury related to the research, please contact the investigator: **Godfrey Rangasammy** **Email:** grangasa@umd.edu **Telephone:** 301-442-1080
Participant Rights	If you have questions about your rights as a research participant or wish to report a research-related injury, please contact:

	University of Maryland College Park **Institutional Review Board Office** **1204 Marie Mount Hall** **College Park, Maryland 20742** **Email:** irb@umd.edu **Telephone: 301-405-0678** This research has been reviewed and approved according to the University of Maryland, College Park IRB procedures for research involving human subjects.
Statement of Consent	By agreeing to participate, you are indicating that you are at least 18 years of age; you have read this consent form or have had it read to you; your questions have been answered to your satisfaction and you voluntarily agree to participate in this research study. You may print/download a copy of this consent form. If you agree to participate, please select "yes" below. ☐Yes ☐No

Appendix G – Email Reminder To Participants

Re: Survey Reminder: Survey of Teacher Practices: The Next Generation of Science Standards (NGSS) in Grade 1-5
From: Godfrey Rangasammy (grangasa@umd.edu)
To: Participant Email Address

Reminder: Survey of Teacher Practices: The Next Generation of Science Standards (NGSS) in Grade 1-5

Dear Participant,

You should have received an email last week regarding my study on how and to what extent the district's grade 1-5 teachers support students on the use the Science and Engineering Practices, specifically, the use and development of models for the purpose of constructing explanations in science instruction. This study is being conducted as part of my dissertation research at the University of Maryland, under the direction of Dr. Margaret J. McLaughlin. Your participation in this survey could offer a potential benefit to the district in determining professional development needs of teachers, as the NGSS is implemented.

This survey should not take longer than 15 minutes. It is anonymous and your participation is voluntary. Upon completion, you will be asked if you would like to participate in a raffle for a chance to win one of fifty $10 electronic Amazon.com gift card. If you chose yes, you will be directed to a secondary survey link that asks for your email address. Your responses to the first survey are not connected to the secondary survey, hence your responses will still remain anonymous.

The last day to submit the survey is DATE

Please use this link to access the survey:

This link is uniquely tied to this survey and your email address. Please do not share nor forward this message.

If this link does not work, please copy and paste the link into your web browser.

Thanking you in advance for completing this survey.

Godfrey Rangasammy
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Appendix H

Teacher Perceived Barriers

	Not a Barrier	Mostly Not a Barrier	Neutral	Somewhat a Barrier	Major Barrier	Mean	SD
My school culture only focuses on Common Core Mathematics and RELA							
Grades 1-5 (f)	47	25	57	89	51	3.27	1.348
Grades 1-5 (%)	17.5	9.3	21.2	33.1	19.0		
Grades 1-2 (f)	15	11	26	48	21	3.40	1.235
Grade 1-2 (%)	12.4	9.1	21.5	39.7	17.4		
Grades 3-5 (f)	32	14	31	41	30	3.16	1.427
Grades 3-5 (%)	21.6	9.5	20.9	27.7	20.3		
Limited instructional time							
Grades 1-5 (f)	36	25	29	80	99	3.67	1.397
Grades 1-5 (%)	13.4	9.3	10.8	29.7	36.8		
Grades 1-2 (f)	13	6	14	37	51	3.88	1.305
Grade 1-2 (%)	10.7	5.0	11.6	30.6	42.1		
Grades 3-5 (f)	23	19	15	43	48	3.50	1.450
Grades 3-5 (%)	15.5	12.8	10.1	29.1	32.4		
My level of understanding of the expectations of NGSS							
Grades 1-5 (f)	50	53	64	81	21	2.89	1.244
Grades 1-5 (%)	18.6	19.7	23.8	30.1	7.8		
Grades 1-2 (f)	14	22	36	40	9	3.07	1.131
Grade 1-2 (%)	11.6	18.2	29.8	33.1	7.4		
Grades 3-5 (f)	36	31	28	41	12	2.74	1.315
Grades 3-5 (%)	24.3	20.9	18.9	27.7	8.1		
My level of understanding of the district’s science instructional resources							
Grades 1-5 (f)	54	57	65	71	22	2.81	1.256
Grades 1-5 (%)	20.1	21.2	24.2	26.4	8.2		
Grades 1-2 (f)	13	29	34	34	11	3.01	1.151
Grade 1-2 (%)	10.7	24.0	28.1	28.1	9.1		
Grades 3-5 (f)	41	28	31	37	11	2.66	1.318
Grades 3-5 (%)	27.7	18.9	20.9	25.0	7.4		
Inadequate Professional Development opportunities to help me understand the NGSS Science and Engineering Practices							
Grades 1-5 (f)	47	50	63	73	36	3.00	1.303
Grades 1-5 (%)	17.5	18.6	23.4	27.1	13.4		
Grades 1-2 (f)	11	22	36	35	17	3.21	1.168
Grade 1-2 (%)	9.1	18.2	29.8	28.9	14.0		

Grades 3-5 (f)	36	28	27	38	19	2.84	1.385
Grades 3-5 (%)	24.3	18.9	18.2	25.7	12.8		

Teacher Perceived Barriers

	Not a Barrier	Mostly Not a Barrier	Neutral	Somewhat a Barrier	Major Barrier	Mean	SD
Inadequate administrator support for science instruction							
Grades 1-5 (f)	78	38	79	45	29	2.66	1.339
Grades 1-5 (%)	29.0	14.1	29.4	16.7	10.8		
Grades 1-2 (f)	30	22	33	25	11	2.71	1.294
Grade 1-2 (%)	24.8	18.2	27.3	20.7	9.1		
Grades 3-5 (f)	48	16	46	20	18	2.62	1.377
Grades 3-5 (%)	32.4	10.8	31.1	13.5	12.2		
Limited instructional materials to include digital devices and science equipment							
Grades 1-5 (f)	30	33	48	83	75	3.52	1.315
Grades 1-5 (%)	11.2	12.3	17.8	30.9	27.9		
Grades 1-2 (f)	10	16	22	36	37	3.61	1.274
Grade 1-2 (%)	8.3	13.2	18.2	29.8	30.6		
Grades 3-5 (f)	20	17	26	47	38	3.45	1.347
Grades 3-5 (%)	13.5	11.5	17.6	31.8	25.7		

Appendix I

Model Inclusion and Instruction

	Never	Rarely	Sometimes	Often	Daily	Mean	SD
Use existing models to construct explanations of phenomenon							
Grades 1-5 (f)	14.00	59.00	98.00	79.00	19.00	3.11	1.00
Grades 1-5 (%)	5.20	21.93	36.43	29.37	7.06		
Grades 1-2 (f)	9.00	32.00	46.00	28.00	6.00	2.92	1.00
Grades 1-2 (%)	7.44	26.45	38.02	23.14	4.96		
Grades 3-5 (f)	5.00	27.00	52.00	51.00	13.00	3.27	0.97
Grades 3-5 (%)	3.38	18.24	35.14	34.46	8.78		
Create a physical model of a scientific phenomenon							
Grades 1-5 (f)	21.00	77.00	106.00	55.00	10.00	2.84	0.96
Grades 1-5 (%)	7.81	28.62	39.41	20.45	3.72		
Grades 1-2 (f)	15.00	40.00	45.00	19.00	2.00	2.61	0.95
Grades 1-2 (%)	12.40	33.06	37.19	15.70	1.65		
Grades 3-5 (f)	6.00	37.00	61.00	36.00	8.00	3.02	0.94
Grades 3-5 (%)	4.1	25.0	41.2	24.3	5.4		
Develop a conceptual model based on data or observations							
Grades 1-5 (f)	23.00	75.00	98.00	61.00	12.00	2.87	1.01
Grades 1-5 (%)	8.55	27.88	36.43	22.68	4.46		
Grades 1-2 (f)	16.00	40.00	39.00	24.00	2.00	2.64	1.00
Grades 1-2 (%)	13.22	33.06	32.23	19.83	1.65		
Grades 3-5 (f)	7.00	35.00	59.00	37.00	10.00	3.05	0.97
Grades 3-5 (%)	4.73	23.65	39.86	25.00	6.76		
Represent relevant components of a phenomenon when developing models							
Grades 1-5 (f)	26.00	48.00	111.00	70.00	14.00	2.99	1.02
Grades 1-5 (%)	9.67	17.84	41.26	26.02	5.20		
Grades 1-2 (f)	19.00	27.00	51.00	21.00	3.00	2.69	1.02
Grades 1-2 (%)	15.70	22.31	42.15	17.36	2.48		
Grades 3-5 (f)	7.00	21.00	60.00	49.00	11.00	3.24	0.95
Grades 3-5 (%)	4.73	14.19	40.54	33.11	7.43		

Appendix J

MANOVA: Grade Level by Model Inclusion and Instruction

Concept	Type III Sum of Squares	df	Mean Square	F	Sig.	Grade Level	Mean	SD
Use Existing Models	8.292a	1	8.292	8.569	0.004	1-2 Grade	2.92	1.00
						3-5 Grade	3.27	0.97
Create Physical Model	11.120b	1	11.12	12.492	0.000	1-2 Grade	2.61	0.95
						3-5 Grade	3.02	0.94
Develop Conceptual Model	11.615c	1	11.615	11.947	0.001	1-2 Grade	2.64	1.00
						3-5 Grade	3.05	0.97
Represent Relevant Components	20.676d	1	20.676	21.454	0.000	1-2 Grade	2.69	1.02
						3-5 Grade	3.24	0.95
Discuss Scientific Models	26.044e	1	26.044	26.253	0.000	1-2 Grade	2.87	0.95
						3-5 Grade	3.49	1.03
Use Simulated Models	15.511f	1	15.511	13.132	0.000	1-2 Grade	2.06	1.02
						3-5 Grade	2.54	1.14
Revise Models	18.432g	1	18.432	17.305	0.000	1-2 Grade	2.12	0.99
						3-5 Grade	2.64	1.06
Identify Strengths/ Limitations	21.496h	1	21.496	19.789	0.000	1-2 Grade	2.11	0.96
						3-5 Grade	2.68	1.10
Write About Observed Models	5.467i	1	5.467	5.964	0.015	1-2 Grade	3.28	0.93
						3-5 Grade	3.57	0.98
Demonstrate Modeling	.525k	1	0.525	0.55	0.459	1-2 Grade	3.74	0.98
						3-5 Grade	3.82	0.97
Modeling to Engage Students	7.092l	1	7.092	6.468	0.012	1-2 Grade	3.25	1.08
						3-5 Grade	3.57	1.02
Revise Own and Others Models	7.813m	1	7.813	6.787	0.010	1-2 Grade	2.68	1.07
						3-5 Grade	3.02	1.08

Note. There is significant difference between grade levels on modeling instruction at the p. <.01 except Demonstrating Modeling is not statistically significant.

Appendix K

MANOVA: Self Contain Classes vs. Departmental by Model Inclusion and Instruction

Concept	Type III Sum of Squares	df	Mean Square	F	Sig.	Dept/SC	Mean	SD
Use Existing Models	7.150	2	3.575	3.665	.027	SC	2.97	.978
						Dept	3.27	.999
Create Physical Model	10.005	2	5.002	5.572	.004	SC	2.67	.931
						Dept	3.04	.966
Develop Conceptual Model	8.827	2	4.414	4.475	.012	SC	2.71	.974
						Dept	3.06	1.015
Represent Relevant Components	7.903	2	3.951	3.892	.022	SC	2.85	1.013
						Dept	3.17	1.002
Discuss Scientific Models	9.333	2	4.667	4.408	.013	SC	3.04	.996
						Dept	3.40	1.066
Use Simulated Models	7.933	2	3.967	3.267	.040	SC	2.19	1.038
						Dept	2.49	1.172
Revise Models	7.146	2	3.573	3.214	.042	SC	2.26	1.036
						Dept	2.58	1.075
Identify Strengths/ Limitations	7.255	2	3.628	3.171	.044	SC	2.27	1.005
						Dept	2.60	1.140
Write About Observed Models	5.658	2	2.829	3.077	.048	SC	3.31	.926
						Dept	3.59	.996
Demonstrate Modeling	3.718	2	1.859	1.964	.142	SC	3.69	1.014
						Dept	3.90	.923
Modeling to Engage Students	6.671	2	3.336	3.027	.050	SC	3.28	1.082
						Dept	3.60	1.011
Revise Own and Others Models	4.182	2	2.091	1.789	.169	SC	2.75	1.094
						Dept	3.00	1.067

Note. There is a significant difference between comprehensive and departmental classrooms on modeling instruction at the p. <.05 level, with exception to Create Physical Modeling, Develop Concept Modeling, and Discuss Modeling significant at the p. < .01 level. Demonstrate Modeling and Revise Models shows no statistical differences. SC= Self- contained classrooms, Dept=departmentalized structure.

Appendix L

MANOVA: Science Coordinator and Teacher Comparison by Model Inclusion

Concept	Type III Sum of Squares	df	Mean Square	F	Sig.	Coord/ PDLT/Tr	Mean	SD
Use Existing Models	9.052	2	4.526	4.674	.010	Coord	3.54	.931
						PDLT	3.29	.849
						Teacher	3.02	1.002
Create Physical Model	9.374	2	4.687	5.207	.006	Coord	3.30	.812
						PDLT	2.88	.781
						Teacher	2.75	.981
Develop Conceptual Model	7.727	2	3.863	3.901	.021	Coord	3.27	.838
						PDLT	3.00	1.061
						Teacher	2.79	1.014
Represent Relevant Components	9.475	2	4.738	4.693	.010	Coord	3.46	.836
						PDLT	3.00	1.000
						Teacher	2.91	1.031
Discuss Scientific Models	6.145	2	3.072	2.870	.058	Coord	3.57	.987
						PDLT	3.35	.931
						Teacher	3.14	1.050
Use Simulated Models	17.013	2	8.506	7.209	.001	Coord	2.89	1.125
						PDLT	2.65	1.222
						Teacher	2.20	1.069
Revise Models	17.257	2	8.629	8.037	.000	Coord	3.00	1.027
						PDLT	2.65	1.222
						Teacher	2.28	1.022
Identify Strengths/ Limitations	12.399	2	6.200	5.513	.005	Coord	2.92	1.038
						PDLT	2.65	1.272
						Teacher	2.32	1.047
Write About Observed Models	6.195	2	3.098	3.376	.036	Coord	3.76	.925
						PDLT	3.71	.772
						Teacher	3.36	.976
Demonstrate Modeling	.806	2	.403	.421	.657	Coord	3.86	.918
						PDLT	3.94	1.029
						Teacher	3.76	.985
Modeling to Engage Students	1.501	2	.750	.669	.513	Coord	3.59	.865
						PDLT	3.53	1.231
						Teacher	3.39	1.075
Revise Own and Others Models	6.160	2	3.080	2.651	.072	Coord	3.19	.995
						PDLT	3.12	1.269
						Teacher	2.79	1.076

Note. A statistical difference obtained at the p. <.05 level for Writing About Models and Developing Conceptual Models. Statistical significance at the p.<.01 was revealed for Using Existing Models, Create Physical Model, Using Simulated Models, Revising Models, and Identify Strengths and Limitations. Tukey HSD Post hoc analysis showed that Science Coordinators demonstrated modeling significantly more so than classroom teachers in each significant finding. PDLT= Professional Development Lead Teacher, Coord= Science Coordinator.

References

Abell, S. K. (2008). Twenty Years Later: Does pedagogical content knowledge remain a useful idea? *International Journal of Science Education*, *30*:10, 1505–1416. doi:10.1080/09500690802187041

American Association for the Advancement of Science (1990). Science for all Americans. New York: Oxford University Press.

American Association for the Advancement of Science (1993). Benchmarks for science literacy. New York: Oxford University Press.

Appleton, K. (1995). Student teachers confidence to teach science: Is more science knowledge necessary to improve self-confidence. International Journal of Science Education, *17*(3), 357–369.

Appleton, K. (2003). How do beginning primary school teachers cope with science? Toward an understanding of science teaching practice. International Journal of Science Education, *33*, 1–25.

ASHE Higher Education Report (2011). Factors in K-12 education that influence the success of racial and ethnic minority students in the STEM Circuit, *36*, 27–52.

Baek, H. & Schwarz, C. V. (2015). The Influence of Curriculum, Instruction, Technology, and Social Interactions on Two Fifth-Grade Students' Epistemologies in Modeling Throughout a Model-Based Curriculum Unit *J Sci Educ Technol* 24: 216. https://doi.org/10.1007/s10956-014-9532-6

Bandura, A. (1977). *Self-efficacy: Toward a unifying theory of behavioral change.* Psychological Review, *84*, 191–215.

Banilower, E., Smith, P. S., Weiss, I., Malzahan, K., Campbell, K., & Weis, A. (2013). *Report of the 2012 National Survey of Science and Mathematics Education.* Chapel Hill, NC: Horizon Research Inc.

Banilower, E. R., Gess-Newsome, J., & Tippins, D. (2014). Supporting the implementation of the next generation science standards (NGSS) through research: Professional development. Retrieved from https://narst.org/ngsspapers/Professional_Development_%20June2014.pdf

Banilower, E. R., Hayes, M. L., Jaffri, A. Z., & Egeland, N. L. (2016). Operationalizing the science practices teacher questionnaire user guide. Chapel Hill, NC: Horizon Research, Inc.

Barton, A. C., Tan, E., & Rivet, A. (2008). Creating hybrid spaces for engaging school science among urban middle school girls. *American Educational Research Journal* 45(1): 68–108

Ben-Peretz, M. (2011). Teacher knowledge: What is it? How do we uncover it? What are its implications for schooling? Teaching & Teacher Education, *27*(1), 3–9. doi:10.1016/j.tate.2010.07.015

Berland, L., & Reiser, B. (2009). Making sense of argumentation and explanation. Science Education. *93*(1), 26–55

Berland, L., Schwarz, C., Krist, C., Kenyon, L., Lo, A., & Reiser, B. (2016). Epistemologies in practice: Making scientific practices meaningful for students. *Journal of Research In Science Teaching, 53*(7), 1082–1112

Berry, A., Friedrichsen, P., & Loughran, J. (2015). Re-examining Pedagogical Content Knowledge in Science Education, Routledge, NY.

Biggers, M., Forbes, C. T., & Zangori, L. (2013). Fostering student sense making in elementary science learning environments: Elementary teachers' use of science curriculum materials to promote explanation construction. Journal of Research in Science Teaching, *50*(8), 989–1017.

Blank, R. K. (2013). Science instructional time is declining in elementary schools: What are the implications for student achievement and closing the gap? Sci. Ed., *97*:830–847. doi:10.1002/sce.21078

Boots, N. K. (2013). *Examining teachers' perspectives on an implementation of elementary engineering teacher professional development* (Ph.D.). Available from ProQuest Dissertations & Theses Full Text. (1508836474).

Brogdon, L. S. (2015). *An exploration of administrators' perceptions of elementary science: A case study of the role of science in two elementary schools based on the interactions of administrators with colleagues, science content and state standards* (Ed.D.). Available from ProQuest Dissertations & Theses Full Text. (1658535424).

Brotman, J. S., & Moore, F. M. (2008). Girls and science: A review of four themes in the science education literature. *Journal of Research in Science Teaching* 45(9): 971-1,002.

Buczynski, S., & Hansen, B. C. (2010). Impact of professional development on teacher practice: Uncovering connections. *Teacher and Teacher Education 26*, 599–607.

Bybee, R. (2010). The teaching of science: 21st Century Perspectives. NSTA Press.

Bybee, R. (2013). Translating the NGSS for classroom instruction. NSTA Press.

Bybee, R. (2014). NGSS and the next generation of science teachers. *Journal of Science Teacher Education*, *25*, 211–221.

Bybee, R. (2015). The BSCS 5E Instructional Model: Creating Teachable Moments. NSTA Press.

Carnegie Corporation of New York and Institute for Advanced Study (2009). The opportunity equation: Transforming mathematics and science education for citizenship and the global economy. Retrieved from https://www.carnegie.org/media/filer_public/80/c8/80c8a7bc-c7ab-4f49-847d-1e2966f4dd97/ccny_report_2009_opportunityequation.pdf

Cavagnetto, A., Hand, B. M., & Norton-Meier, L. (2010). The nature of elementary student science discourse in the context of the science writing heuristic approach. *International Journal of Science Education*, *32*(4), 427–449. doi:10.1080/09500690802627277

Cheuk, T. (2012). Comparison of the three standards: CCSS-ELA, CCSS-Mathematics, and NGSS. Retrieved from http://ell.stanford.edu/content/science

Clevenger-Bright, M., & McDiarmid, W. G. (2008). Chapter 9, Rethinking teacher capacity. *Handbook of Research on Teaching Education: Enduring Questions in Changing Contexts* (3).

Cochran-Smith, M., Fieman-Nemser, S., & McIntyre D. J. (2008). *Handbook of Research on Teacher Education: Enduring Questions in Changing Contexts* (3).

Cohen, D. K., & Hill, H. C. (2000). Instructional policy and classroom performance: The mathematics reform in California. Teachers College, Columbia University, *102*(2) 294–343.

Cooper, M. (2013). Chemistry and the next generation of science standards. *The Journal of Chemical Education*, *27*(2), 183–198.

Corvo, A. F. (2014). *Utilizing the national research council's (NRC) conceptual framework for the next generation science standards (NGSS): A self-study in my science, engineering, and mathematics classroom* (Ph.D.). Available from ProQuest Dissertations & Theses Full Text. (1540804951).

Darling-Hammond, L., & McLaughlin, M. W. (1995). Policies that support professional development in an era of reform. *Phi Delta Kappan 76*, 8: 597–604.

Darling-Hammond, L. (1997). Doing What Matters Most: Investing in quality teaching. New York. The National Commission on Teaching and America's Future (NCTAF).

Darling-Hammond, L., Chung Wei, R., Andree, A., Richardson, N., & Orphanos, S. (2009). *Professional learning in the learning profession: A status report on teacher development in the United States and abroad*. Oxford, OH: National Staff Development Council.

Darling-Hammond, L. (2000). Teacher quality and student achievement: A review of state policy evidence. *Educational Policy Analysis Archives*, *8*(1).

Darling-Hammond, L., Bae, S., Cook-Harvey, C.M., Lam, L., Mercer, L., Podolsky, A., Stosich, E. L. (2016). *Pathways to New Accountability Through the Every Student Succeeds Act* (Palo Alto: Learning Policy Institute, 2016). Retrieved from: http://learningpolicyinstitute.org/our-work/publications-resources/ pathways-new-accountability-every-student-succeeds-act

Dervin, B. (1998). Sense-making theory and practice: an overview of user interests in knowledge seeking and use. *Journal of Knowledge Management, 2*(2) 36-46.

Dervin, B. (1983). An Overview of Sense-making Research: Concepts, Methods, and Results to Date, Int'l Communication Assoc., 1983. Retrieved from http://communication.sbs.ohio-state.edu/sense-making/art/artlist.html

District Q Grants Office (2010). Grants & Financial Management Office, District Q

District Q Science Office (2017). K-12 Science Office, District Q

District Q Transition Team Report (2014). A report of the Transition Team as specified in Goal 5 of the Chief Executive Officer's Entry Plan: Establish a Transition Team to Conduct a Thorough Review of the System, District Q

Dobbie, W., Fryer, R. G., & Fryer Jr. G. (2011). Are high-quality schools enough to increase achievement among the poor? Evidence from the Harlem Children Zone. *American Economic Journal: Applied Economics 3*(3), 158-187.

Dogan, N., & Abd-El-Khalick, F. (2008). Turkish grade 10 students' and science teachers' conceptions of nature of science: A national study. *Journal of Research in Science Teaching, 45*(10), 1083–1112.

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (Eds.), (2007). *Taking science to school: Learning and teaching science in grades K-8*. Washington, DC: National Academies Press.

Enfield, M., Smith, E. L., & Grueber, D. J. (2008). “A sketch is like a sentence”: Curriculum structures that support teaching epistemic practices of science. *Science Education 92*(4): 608-630.

Firestone, W. A., Mangin, M. M., Martinez, M. C., & Polovsky, T. (2005). Leading coherent professional development: A comparison of three districts. *Educational Administration Quarterly, 41*(3), 413–448.

Fishman, B., Marx, R., Best, S., & Tal, R. (2003). Linking teacher and student learning to improved professional development in systemic reform. Teaching and Teacher Education, *19*(6), 643–658.

Fleer, M. (2009). Supporting scientific conceptual consciousness or learning in a “roundabout way” in play based contexts. International Journal of Science Education, *31*(8), 1069-1089. doi:10.1080/09500690801953161

Forbes, C. T., Biggers, M., & Zangori, L. (2013). Investigating essential characteristics of scientific practices in elementary learning environments: The Practices of Science Observation Protocol (P-SOP). School Science and Mathematics, *4*(113), 180–190.

Forbes, C. T., & Davis, E. A. (2010). Curriculum design for inquiry: Preservice elementary teachers’ mobilization and adaptation of science curriculum materials. *Journal of Research in Science Teaching*, *47*(7), 820–839.

Forbes, C. T., Vo, T., Zangori, L., & Schwartz, C. (2015). Using models scientifically. Science and Children, *53*(2), 42–49. Retrieved from http://search.proquest.com/docview/1720442778?accountid=14696

Foster, D. C. (2006). A qualitative case study to identify possible barriers that limit effective elementary science education. (Ph.D., Capella University). ProQuest Dissertations and Theses, (304909748).

Gallenstein, N. (2005). Engaging young children in Science and mathematics. *Journal of Elementary Science Education, 17,* 27–41.

Garet, M. S., Porter, A. C., Desimone, L., Birman, B. F., & Yoon, K. S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal, 38*(4), 915–945. doi:10.3102/00028312038004915

Gay, L. R., Mills, G. E., & Airasian, P. (2006). Educational research: Competencies for analysis and applications. Upper Saddle River, NJ: Pearson Merrill Prentice Hall.

Gess-Newsome, J. (2015). A model of teacher professional knowledge and skill, including PCK: Results of the thinking from the PCK Summit. Re-examining Pedagogical Content Knowledge in Science Education. 28-4

Gess-Newsome, J., & Lederman, N. G. (1993). Preservice biology teachers' knowledge structures as a function of professional teacher education: A year-long assessment. *Science Education*, *77*(1), 24-45.

Gess-Newsome, J., & Lederman, N. G. (1999). Pedagogical content knowledge: An introduction and orientation. (6), pp. 3–17. Science and Technology Education Library.

Gettinger, M. (1985). Time allocated and time spent relative to time needed for learning as determinants of achievement. Journal of Educational Psychology, *77*(1), 3-11.

Griffith, G. W. (2009). *The initial impact of no child left behind with a focus on time for elementary science and equity in science, math, and reading* (Ph.D.). Available from ProQuest Dissertations & Theses Full Text. (304914750).

Grossman, Pamela L. (1990). The making of a teacher: Teacher Knowledge and Teacher Education. NY: Teachers' College Press.

Guskey, T. R. (2003). Professional development that works: What makes professional development effective? *Phi Delta Kappan, 84*(10), 748.

Guskey, T. R., & Yoon, K. S. (2009). What works in professional development? Phi Delta Kappan, *90*(7), 485–500.

Haag, S., & Megowan, C. (2015). Next generation science standards: A national mixed-methods study on teacher readiness. *School Science and Mathematics, 115*(8), 416–426. doi:10.1111/ssm.12145

Hakuta, K., Santos, M., & Fang, Z. (2013). Challenges and Opportunities for Language Learning in the Context of the CCSS and the NGSS. *Journal of Adolescent & Adult Literacy*, *56*(6), 451–454. doi:10.1002/JAAL.164

Hanuscin, D. L., Lee M. H., & Akerson, V. L. (2008). Elementary teachers' pedagogical content knowledge for teaching the nature of science. *Sci. Ed., 95*(1) 145-167. doi:10.1002/sce.20404

Hapgood, S., Magnusson, S. J., & Palincsar, A. S. (2004). Teacher, text, and experience: A case of young children's scientific inquiry. The Journal of

Learning Sciences, *13*(4), 455–505. Retrieved from http://www.jstor.org/stable/1466917

Hardy, I., Jonen, A., Moller, K., & Stern, E. (2006). Effects of instructional support within constructivist learning environments for elementary school students' understanding of "floating and sinking." *Journal of Educational Psychology*, *98*(2), 307–325.

Hargraves, A., & Fullan, M. (2012). *Professional capital: Transforming teaching in every school.* New York: Teachers College Press.

Hayes, K. N. (2014). *Equity in elementary science education: A study of institutional and policy factors*. (Ph.D., University of California, Davis). ProQuest Dissertations and Theses, (1615888866).

Hayes, K. N., Lee, C. S., & DiStefano, R. et al. *J Sci Teacher Educ* (2016) *27*: 137. doi:10.1007/s10972-016-9448-5

Hedman, R., & Passmore, C. (2013). *Understanding Modeling, the NGSS practices and the moon.* Retrieved from http://saspcsus.pbworks.com/w/page/70331043/CSTA2013b

Hedman, R., Schwartz, K., & Munson, L. (2013). Conservation of Matter: A modeling Approach. Retrieved from http://saspcsus.pbworks.com/w/page/70319851/CSTA2013A

Heller, J. I., Daeler, K. R., Wong, N., Shinohara, M., & Miratrix, L. W. (2012). Differential effects of three professional development models on teacher knowledge and student achievement in elementary science. *Journal of Research in Science Teaching, 49*(3), 333–362.

Hewson, P. W. (2007). Teacher professional development in science. In *Handbook of research in science education*, S. K. Abell & N. J. Lederman (Eds.), 1179–1203. Mahwah, NJ: Lawrence Erlbaum Associates.

Hill, H. (2007). Learning in the teaching workforce. *Future of Children, 17*(1), 111–128.

Hill, L., & Betz, D. (2005). Revisiting the retrospective pretest. *American Journal of Evaluation*, 26(4), 501-517.

Jimenenez-Aleixandre, M. P., Rodriguez, A. B., & Duschl, R. A. (2002). “Doing the lesson” or “doing science”: Argument in high school genetics. *Science Education*, *84*, 757–792.

Juttner, M., Boone, W., Park, S., & Neuhaus, B. J. (2013). Development and use of a test instrument to measure biology teachers’ content knowledge (CK). *Educational Assessment, Evaluation and Accountability, 25*(1), 45–67. doi:10.1007/s1109-013-9157-y

Judson, E. (2013). The relationship between time allocated for science in elementary schools and state accountability policies. *Sci. Ed.*, 97: 621–636. doi:10.1002/sce.21058

Kaya, O. N. (2009). The nature of relationships among the components of pedagogical content knowledge of preservice science teachers: ‘ozone layer depletion’ as an example. *International Journal of Science Education*, *31*(7), 961–988. doi:10.1080/09500690801911326

Kelley, K., Clark, B., Brown, V., & Sitzia, J. (2003). Methodology Matters: Good practice in the conduct and reporting of survey research. *International Journal of Quality in Health Care, 15*(3), 261–266.

Kennedy, M. M. (1999). Form and substance in mathematics and science professional development. NISE (National Institute of Science Education) brief, *3*(2), 2–6.

Kenyon, L., Schwarz, C., & Hug, B. (2008). The benefits of scientific modeling. *Science and Children, 46*(2), 40–44. Retrieved from http://www.jstor.org.proxy-um.researchport.umd.edu/stable/43174980

Kesidou, S., & Roseman, J. E. (2002). How well do middle school science programs measure up? Findings from Project 2016's curriculum review. *Journal of Research in Science Teaching, 39*(6), 522–549.

Khan, R. S. (2005). *Implementation of national science education standards in suburban elementary schools: Teachers' perceptions and classroom practices.* (Ph.D., University of New Orleans). ProQuest Dissertations and Theses, (304989810).

Klein, G., Moon, B., & Hoffman, R. (2006). Making sense of sensemaking 1: Alternative Perspectives. IEEE Intelligent Systems, *2*(4), 70–73

Koba, S., & Wojnowski, B. (2013). Exemplary Science: Best practices in professional development. NSTA Press.

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 Teacher, 79*, 38–41.

Lazzaro, C. C. (2015). *On the consideration of adoption and implementation of the next generation science standards in a local-control context: Supporting the epistemology of science through education policy* (Ph.D.). Available from ProQuest Dissertations & Theses Full Text. (1659817692).

Lee, O., Adamson, K., Maerten-Rivera, J., Lewis, S., Thorton, C., & LeRoy, K. (2008). Teachers' perspectives on a professional development intervention to improve science instruction among English language learners. *Journal of Science Teacher Education, 19*(1), 41–67.

Lee, O., Deaktor, R. A., Hart, J. E., Cuevars, P., & Enders, C. (2005). An instructional intervention's impact on the science and literacy achievement of culturally and linguistically diverse elementary students. *Journal of Research in Science Teaching* 42(8): 857-887.

Lehrer, R., & Schauble, L., (2006). Scientific thinking and science literacy. Supporting development in learning contexts. In W. Damon, R. M. Lerner, K. A. Renninger, & I. E. Sigel (Eds.), *Handbook of child psychology, 6*(4), 153–196. Hoboken, NJ: John Wiley and Sons.

Loucks-Horsley, S., Love, N., Stiles, K. E., Mundry, S., & Hewson, P. W. (2003). *Designing professional development for teachers of science and mathematics, 2nd edition*. Thousand Oaks, CA: Corwin Press.

Loucks-Horsley, S., Love, N., Stiles, K. E., Mundry, S., & Hewson, P. W. (2010). *Designing professional development for teachers of science and mathematics, 2nd edition*. Thousand Oaks, CA: Corwin Press.

Loucks-Horsley, S., & Matsumoto, C. (1999). Research on professional development for teachers of mathematics and science: The state of the scene. *School Science and Mathematics, 99*(5), 258–271. doi:10.1111/j.1949-8594.1999.tb17484.x

Magnusson, S., Krajick, L., & Borko, H. (1999). Nature, sources and development of pedagogical content knowledge. In J. Gess-Newsome, & N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 95–132). Dordrecht: Kluwer.

Magnusson, S., & Palincsar, A. M. (2005). Teaching to promote the development of scientific knowledge and reasoning about light at the elementary school level. In M. S. Donovan, & J. D. Bransford (Eds.), How students learn: Science in the classroom (pp. 421–474). Washington, DC: National Academy Press.

Mantzicopoulos, P., Patrick, H., & Samarapungavan, A. (2008). Young children's motivational beliefs about learning science. *Early Childhood Research Quarterly, 23,* 378–394.

Maryland Report Card (2015). Retrieved from http://reportcard.msde.maryland.gov/

McNeill, K. L. (2011). Elementary students' views of explanation, argumentation, and evidence, and their abilities to construct arguments over the school year. Journal of Research in Science Teaching, *48*(7), 793–823.

Meier, L. T. (2006). *The effect of school culture on science education at an elementary school: An ethnographic case study. (Ed.D., University of Central Florida).* ProQuest Dissertations and Theses, (304944651).

Metz, K. (2011). Disentangling robust developmental constraints from instructionally mutable: Young Children's epistemic reasoning about a study of their own design. Journal of Learning Sciences, *20*(1), 50–110.

Muir, K. A. (2003). *Challenging multicultural science education: Stories of urban elementary teachers implementing science standards*. (Ph.D., University of California, Los Angeles). ProQuest Dissertations and Theses. (305351034).

MSDE (2010). Maryland's race to the top (RTTT). Retrieved from http://archives.marylandpublicschools.org/MSDE/programs/race_to_the_top/

MSDE (2013). Maryland Next Generation Science Standards Implementation and Planning Document. Retrieved from http://mdk12.msde.maryland.gov/share/VSC/UpdatedNGSS_IT.pdf

MSDE, Certification Division (2016). Retrieved from http://www.dsd.state.md.us/comar/comarhtml/13a/13a.12.02.04.htm

MSDE Blackboard (2016). Retrieved from https://msde.blackboard.com/webapps/portal/execute/tabs/tabAction?tab_tab_group_id=_104_1

MSDE Professional Standards for Educational Leaders (2017). Why PSEL? Retrieved from http://marylandpublicschools.org/about/Pages/OTPE/PSEL.aspx

National Academy Of Engineering (2008). Grand challenges for engineering. National Academy of Sciences.

National Center for Education Statistics (2011). The condition of education. Retrieved from https://nces.ed.gov/pubs2011/2011033.pdf

National Commission on Teaching and America's Future (1996). What matters most: Teaching for America's Future. New York: Author.

National Research Council (2012). *A Framework For K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas,* National Academies Press.

National Research Council (2015). *Guide to implementing the next generation of science standards.* National Academy Press.

National Research Council (1996). National Science Education Standards. Washington, DC: National Academy Press.

National Research Council (2001). *Educating teachers of science, mathematics, and technology: New practices for the new millennium.* Washington, DC: National Academy Press.

National Science Board (2012). Science and Engineering Indicators. National Science Foundation. Retrieved from https://www.nsf.gov/statistics/seind12/

National Science Board (2014). Science and Engineering Indicators. National Science Foundation. Retrieved from https://www.nsf.gov/statistics/seind14/

National Science Board (2016). Science and Engineering Indicators. National Science Foundation. Retrieved from https://www.nsf.gov/statistics/2016/nsb20161/#/

National Science Foundation (1996). *Lacking a clear focus, U.S. Science and Mathematics courses cover many subjects but provide little depth, Press Release 96-059* Retrieved from: http://www.nsf.gov/news/news_summ.jsp?cntn_id=101796

National Science Foundation (2006). America's Pressing Challenge — Building a Stronger Foundation (NSB-06-02). Retrieved March 17, 2016, from http://www.nsf.gov/statistics/nsb0602/nsb0602.pdf

National Science Foundation (2008). Grant Awards, retrieved from http://www.nsf.gov/awardsearch/showAward?AWD_ID=0831970

National Science Teachers Association (2013). NSTA Position Statement: The Next Generation of Science Standards. Retrieved from http://www.nsta.org/about/positions/ngss.aspx

National Science Teachers Association (2017). NSTA Adoption States: The Next Generation of Science Standards. Retrieved from http://ngss.nsta.org/About.aspx

NGSS Lead States (2013). *Next Generation Science Standards: For States, By States*. Washington, DC: The National Academies Press.

NGSS Lead States (2013). *Next Generation Science Standards Appendices: For States, By States*. Washington, DC: The National Academies Press. Retrieved from http://www.nextgenscience.org/resources/ngss-appendices

Nollmeyer, G. E. (2014). *Measuring elementary educators' understanding and readiness for implementing a new framework in science education* (Ed.D.). Available from ProQuest Dissertations & Theses Full Text. (1564038312).

North, S. G. (2013). *An examination of the challenges influencing science instruction in Florida elementary classrooms* (Ph.D.). Available from ProQuest Dissertations & Theses Full Text. (1507461658).

Nowicki, B. L., Sullivan-Watts, B. K., Shim, M. K., & Young, B. J. (2013). Sustaining reform-based science teaching of preservice and inservice elementary teachers. *Journal of Science Teacher Education, 24*(5), 879–905.

Organization for Economic Co-operation and Development, OECD (2012). Programme for international student assessment (PISA). Retrieved from http://www.oecd.org/pisa/keyfindings/pisa-2012-results.htm

Organization for Economic Co-operation and Development, OECD (2013). Programme for international student assessment (PISA). Retrieved from http://www.oecd.org/pisa/keyfindings/pisa-2012-results-volume-iii.htm

Organization for Economic Co-operation and Development, OECD (2009). *Doing better for children*. Programme for international student assessment (PISA). Retrieved from http://www.oecd.org/els/family/doingbetterforchildren.htm

Page, S. (2007). The difference: How the power of diversity creates better groups, firms, schools, and societies. Woodstock, England: Princeton University Press.

Park, S., Jang, J., Chen, Y., & Jung, J. (2011). Is pedagogical content knowledge (PCK) necessary for reformed science teaching? Evidence from an Empirical Study. *Research in Science Education, 41*(2), 245–260.

Passmore, C., Stewart, J., & Cartier, J. (2009). Model-Based Inquiry and School Science: Creating Connections. School Science and Mathematics, *109*: 394–402. doi:10.1111/j.1949-8594.2009.tb17870.x

Passmore, C. M., & Svoboda, J. (2012). Exploring opportunities for argumentation in modeling classrooms. International Journal of science Education, *34*(10), 1535–1554. doi:10.1080./09500693.2011.577842

PCAST (2010). *Report to the president. Prepare and inspire: K-12 Education in science, technology, math and engineering (STEM) for America's future,* Executive Office of the President.

PhET Interactive Simulations (2017). Energy forms and changes, University of Colorado, Retrieved October 2017 from https://phet.colorado.edu/en/simulation/legacy/energy-forms-and-changes

Porter, A. C. (2012). Educational policy breakfast series: Teacher Quality/Effectiveness: Defining, developing, and assessing policies and practices. New York: New York University.

Raizen, S., & Michelsohn, A. M. (1994). *The future of science in elementary schools: Educating prospective teachers.* San Francisco, CA. Jossey-Bass.

Reiser, B. J., Berland, L. K., & Kenyon, L. (2012). Engaging students in the scientific practices of explanation and argumentation. *The Science Teacher 79*(4), 34–39; *Science Scope 35*(4), 6–11; *Science and Children, 49*(4), 8–13.

Reiser, B. J. (2013). What professional development strategies are needed for successful implementation of the next generation science standards? Educational Testing Service (ETS).

Rinehart, R., Duncan, R. G., & Chinn, C. A. (2014). A scaffolding suite to support evidence-based modeling and argumentation. *Science Scope, 38*(4), 70–7.

Roychoudhury, A., & Kahle, J. B. (1999). Science teaching in the middle grades: Policy Implications for teacher education and systemic reform. *Journal of Teacher Education. 50*:278–289.

Samarapungavan, A., Mantzicopoulos, P., & Patrick, H. (2008). Learning science through inquiry in kindergarten? *Science Education*, *92*(5), 868–908.

Sampson, V., Enderle, P., Grooms, J., & Witte, S. (2013). Writing to learn and learning to write during school science laboratory: Helping middle and high school students develop argumentative writing skills as they learn core ideas. *Science Education*, *97*(5), 643–670.

Schwarz, C., Reiser, B., Davis, L., Kenyon, A., Archer, D., Fortus, Y., Schwartz, B., Hug, B., & Krajick, 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.

Schwarz, C., Passmore, C., & Reiser, B. (2017). *Helping students make sense of the world using next generation science and engineering practices*. NSTA Press, Arlington, VA.

Shallcross, T., Spink, E., Stephenson, P., & Warwick, P. (2002). How primary trainee teachers perceive the development of their own scientific knowledge: Links between confidence, content and competence? *International Journal of Science Education*, *24*(2), 1293–1312.

Shulman, L. S. (1986). "Those who understand: Knowledge growth in teaching." *Educational Researcher* Feb. 1986: 4-14. (AERA Presidential Address).

Shulman, L. S. (2005). "Signature pedagogies in the professions." *Daedalus* 134.3: 52-59.

Shulman, L. S. (2015). PCK: It's Genesis and Exodus. In *Re-examining Pedagogical Content Knowledge in Science Education*, Routledge, NY.

Smith, C., Wiser, M., Anderson, C. W., & Krajcik, J. (2006). Implications for children's learning for assessment: A proposed learning progression for matter and the atomic molecular theory. Measurement, *14*(1 and 2), 1–98.

Smith, D. C., & Neale, D. C. (1989). The construction of subject matter knowledge in primary science teaching. *Teaching & Teacher Education, 5*(1), 1–20.

Songer, N. B., & Wenk Gotwals, A. (2012). Guiding explanation construction by children at the entry points of learning progressions. Journal of Research in Science Teaching, *49*(2), 141–165.

Spillane, J. P., & Callahan, K. A. (2000). Implementing state standards for science education: What district policy makers make of the hoopla. *Journal of Research in Science Teaching*, *37*(5), 401–525.

Supovitz, J. A., & Turner, H. M. (2000). The effects of professional development on science teaching practices and classroom culture. *Journal of Research in Science Teaching, 37*(9), 963–980.

The Concord Consortium (2017). Phase-change (a multi-page activity): interactive, scaffolded model, MOLO: Molecular logic. Retrieved October 2017, from http://molo.concord.org/database/activities/180.html

Thomas, T. A. (2014). *Elementary teachers' receptivity to integrated science, technology, engineering, and mathematics (STEM) education in the elementary grades* (Ed.D.). Available from ProQuest Dissertations & Theses Full Text. (1557706624).

Tice, C. J. (1999). *The integration of science process skills in elementary science, math, and language arts: A case study of the effect upon student science achievement* (Ph.D.). Available from ProQuest Dissertations & Theses Full Text. (304551812).

Tienken, C. H. (2014). PISA problems. *AASA Journal of Scholarship and Practice,* 10(4), 4-18

Tilgner, P. J. (1990). Avoiding science in elementary school. Science Education, *74*(4), 421–431.

TNTP Reimagine Teaching (2015). *The Mirage: Confronting the hard truth about our quest for teacher developmen*t, retrieved from http://tntp.org/assets/documents/TNTP-Mirage_2015.pdf

Trygstad, P., Smith, P., Banilower, E., & Nelson, M. (2013). The Status of Elementary Science Education: Are We Ready for the Next Generation National Study on NGSS Readiness School Science and Mathematics Science Standards? Horizon Research, Inc. Supported by a National Science Foundation grant, DUE-09281.

University of Maryland, Baltimore Campus (2016). Master of Arts in Education (MAE). Retrieved from http://www.umbc.edu/mae/programs.php

Van Driel, J. H., De Jong, O., & Verloop, N. (2002). The development of preservice chemistry teachers' pedagogical content knowledge. Science Education, *86*(4), 572.

Waters, J. T., Marzano, R. J., & McNulty, B. (2003). Balanced leadership: What 30 years of research tells us about the effect of leadership on student achievement. Aurora, CO: McREL.

Weick, K. E., Sutcliffe, K. M., & Obstfeld, D. (2005). Organizing and the process of sensemaking. Organization Science *16*(4):409–421. http://dx.doi.org/10.1287/orsc.1050.0133

Weiss, I. R., & Pasley, J. D. (2006). Scaling up instructional improvement through teacher professional development: Insights from the Local Systemic Change Initiative. *Consortium for Policy research in Education (CPRE) policy Briefs*, March: RB-44.

Wiggins, G., & McTighe, J. (2005). Understanding By Design. ASCD. Alexandria, VA.

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

Wilson, S., Floden, R., & Ferrini-Mundy, J. (2001). *Teacher preparation research: Current knowledge, gaps, and recommendations.* Seattle, WA: The Center for Teaching and Policy, The University of Washington.

Windschitl, M., Thompson, J., & Braaten, M. (2008). Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school investigations. *Science Education*, *92*(5), 941–967.

Windschitl, M., & Thompson, J. J. (2013). The modeling toolkit. *The Science Teacher, 80*(6), 63-69. Retrieved from http://search.proquest.com/docview/1437615573?accountid=14696

Zangori, L., Forbes, C. T., & Biggers, M. (2013). Preservice elementary teachers and explanation construction: Knowledge-for-practice and knowledge-in-practice. *Science Education, 97*(2), 310–330.

Zangori, L., Forbes, C. T., & Biggers, M. (2013). Fostering student sense-making in elementary learning environments: Elementary teachers' use of science curriculum materials to promote explanation construction. *Journal of Research In Science Teaching*, *50*(8), 989–1017.