Next Generation Science Standards: Veteran high school science teachers' transfer of learning from formal, nonformal, and informal professional development

by

Anne M. Krebs

B.S., Truman State University, 1988
M.A.E, Truman State University, 1989

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

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Department of Educational Leadership
College of Education

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Abstract

Twenty states, including Kansas, expect science teachers to utilize the content and learning experiences outlined by the Next Generation Science Standards (NGSS). These standards specify student-centered teaching and learning through inquiry, science and engineering practices, and scientific argumentation. Current science teachers may find it necessary to shift or modify teaching practices to accommodate NGSS expectations. This qualitative multi-case study was designed to explore the experiences of three veteran high school science teachers as they learn about NGSS and transfer NGSS knowledge and teaching strategies to classroom practice. The case study focused on three areas: 1) the participants' description of NGSS, 2) the influence of the mode of learning delivery — formal professional development, nonformal professional development, and informal learning, and 3) the transfer of NGSS knowledge to teaching practice. Study findings were based on semi-structured interviews, classroom observations, and analysis of documents — professional development notes, class handouts, and grading rubrics. Data were analyzed with a theoretical framework of interpretivism and symbolic interactionism, respecting each participant's assignment of value and meaning. The conceptual framework incorporated NGSS; learning delivery mode — formal, nonformal, and informal; and transfer of learning to assess participants' application of learning to teaching practice. A cross-case analysis found that teachers, although they did not utilize NGSS terminology regularly, transferred NGSS knowledge to classroom practice unless the teaching practices conflicted with a pre-existing teaching pedagogy. The study results have implications for professional development staff, school administrators, and science teachers.

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Approved by:

Major Professor
Royce Ann Collins, Ph.D.

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Dedication

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Chapter 1: Introduction

Introduction

Science teachers are being asked to improve science teaching so all students will be able to demonstrate greater science knowledge and scientific literacy (National Research Council, 2013a; Rutherford & Ahlgren, 1990). For 20 states, including Kansas, this has resulted in adoption of the Next Generation Science Standards (NGSS) (NGSS adoption map, 2014), a nationally recognized program for K-12 science education that integrates science content with science and engineering practices (National Research Council, 2013a). This updated approach to science — a coherent and progressive growth of knowledge, understanding, and explanation — demands that inservice teachers shift daily practices away from traditional science instruction towards student-centered science instruction that incorporates science and engineering practices as an integral part of teaching practices (National Research Council, 2015; Reiser, 2013; Wilson, 2013). Continuing science teacher education or professional development (PD) is the forum for most inservice teachers' exposure to NGSS content and teaching practices. Each participating teacher's NGSS classroom practice is influenced by PD, personal preferences, previous training, and many other factors (Banilower et al., 2013; National Research Council, 2015).

Next Generation Science Standards

The NGSS authors did not provide a curriculum for science teachers to follow (National Research Council, 2012, 2013a; Pruitt, 2014), but included grade level standards to apply to all students that incorporates three components — disciplinary core ideas, crosscutting concepts, and science and engineering practices (Duncan & Cavera, 2015; National Research Council, 2013a). Together, these three dimensions suggest ways of teaching science while integrating science and engineering practices as learning activities and as performance expectations (Duncan

& Cavera, 2015; National Research Council, 2015; Pruitt, 2014). Next Generation Science Standards, across the grade levels and content areas, include requirements for inquiry investigation, science and engineering practices, and scientific argumentation (Duncan & Cavera, 2015; National Research Council, 2013a).

Throughout the writing process the NGSS designers emphasized the challenges of NGSS implementation and adoption (National Research Council, 2012, 2013b, 2015; Pruitt, 2014). Changes were required at all elements of the education system: classroom instruction, teacher and leader training, curriculum materials, assessment, networks and partnerships, and state and district policy (National Research Council, 2015). Inservice teachers reported a lack of confidence and experience with the necessary shift from a traditional didactic teaching format and prescriptive laboratory experience (Banilower et al., 2013) to the inquiry, science and engineering practices, and scientific argumentation required by NGSS. Classroom teachers assumed the biggest portion of the responsibility for NGSS implementation, but all involved in the process — classroom teachers, building leaders, district curriculum representatives, and state education department agents — need to be included in multi-year PD plans that addressed NGSS content, teaching practices, and assessment (National Research Council, 2015).

The Next Generation Science Standards apply to all levels of science instruction in K-12 schools (National Research Council, 2013a). Secondary science teachers have the largest section of standards and content across the four science disciplines included in NGSS: life science; physical science; earth and space science; and engineering (Pruitt, 2014). The inclusion of science and engineering practices, inquiry, and scientific argumentation is particularly challenging for many teachers (Boesdorfer & Greenhalgh, 2014; Gutierez, 2015; Wilson, 2013).

Current science teachers are likely to require PD on all aspects of NGSS content and instruction, particularly on those changes from a didactic presentation of K-12 science.

Science Teacher Learning Experiences

Science teacher education, whether pre-service or continuing PD, follows no specific pattern or minimal national requirements (Wilson, Floden, & Ferrini-Mundy, 2001). Pre-service science teacher education programs are established by each state's department of education and include varying levels of specificity and rigor in pre-service courses (Wilson et al., 2001). Most states require courses in a content area, pedagogy, classroom management, assessment, and special education as part of the pre-service teacher curriculum (Educator Licensure Pre-Approved PEL Coursework-IL Institutions, 2017; Iowa Administrative Code, 2017; Olson, Tippett, Milford, Ohana, & Clough, 2015). That same lack of consistency persists in the state requirements for teacher certification renewal. Teachers are required to demonstrate teaching proficiency and earn continuing education points, although exact amounts vary from state-to-state (Olson et al., 2015).

Most secondary science teachers receive continuing education, or PD, through a combination of formal, nonformal and informal adult learning experiences (Banilower et al., 2013; Borko, 2004). Formal learning experiences include college courses or other institutionalized training opportunities (Merriam, Caffarella, & Baumgartner, 2007). Researchers identified several key PD components that maximized teacher participant interest and learning, particularly for formal learning experiences: (1) teachers were partners in PD (Herrington & Daubenmire, 2016), (2) PD was collaborative (Garet, Porter, Desimone, Birman, & Yoon, 2001; van Driel, Meirink, van Veen, & Zwart, 2012) and (3) PD was of adequate duration (Garet et al., 2001; Supovitz & Turner, 2000).

While important to science teacher education, formal learning experiences represent a small percentage of the learning experiences for most science teachers (Banilower et al., 2013). Nonformal and informal learning experiences are much more frequent and productive for most practicing science teachers (Banilower et al., 2013). Nonformal education is often delivered through national or regional teacher conferences offering workshops on NGSS and associated teaching practices. Online webcasts offer more opportunities for nonformal learning (Banilower et al., 2013; National Science Teachers Association, 2017). Often overlooked, "informal learning refers to the experiences of everyday living from which we learn something" (Merriam et al., 2007, p. 24). For science teachers informal learning includes, among other examples, learning from classroom experiences, reflection after teaching activities, and conversations with teaching colleagues and administrators (Banilower et al., 2013). While not often acknowledged as a learning experience, this incidental or informal learning fulfills the key components of quality PD: collaborative, social, of adequate duration, and active (Garet et al., 2001; Herrington & Daubenmire, 2016; van Driel et al., 2012). Regardless of the format for the PD, the individual teacher (the learner) determines what transfers from PD to the classroom and how that knowledge or information is utilized (Enderle et al., 2014; Hewson, 2007). Only the learner (the teacher) has control over how he or she will modify or adapt teaching practices. PD opportunities can provide information and models of NGSS-appropriate instruction and activities; the learner will be the one to determine when and how PD information is put into practice.

Next Generation Science Standards and Science Teacher Professional Development

Published in April 2013 (National Research Council, 2013a) and adopted by Kansas in June of that same year (Kansas State Department of Education, 2014), NGSS requires science educators to update, modify, or — in some instances — completely change the way science is taught in the K-12 classroom (Pruitt, 2014; Reiser, 2013; Wilson, 2013). The NGSS developers and the science education community recognized the tremendous impact this would have on science educators and advocated for system-wide and sustained PD program (National Research Council, 2015; Pruitt, 2014; Wilson, 2013). With, or without, NGSS-specific PD, classroom teachers are expected to implement NGSS content and science practices. All involved with science education, from the classroom teacher to building and district administrators, should participate in recurring PD as the district, building, and classroom concept of NGSS instruction and assessment is developed (National Research Council, 2015; Pruitt, 2014). As the district and building vision and understanding of NGSS evolves, each teacher will develop his or her personal understanding of NGSS and its place in the classroom (Bowman, Jr. & Govett, 2015; Herrington & Daubenmire, 2016).

With the publication and state adoption of NGSS, current science teachers have reported a lack of confidence with the shift from traditional, often didactic, teaching methods to a more inquiry-based classroom (Banilower et al., 2013). The expansion of the role of scientific argumentation and the inclusion of engineering practices was especially concerning for many teachers (Boesdorfer & Greenhalgh, 2014; Wilson, 2013). The National Research Council (2015) and the other organizations involved in the development of NGSS (National Research Council, 2013a) anticipated these challenges for practicing teachers, school administration, and state officials and included recommendations for sustained, system-wide PD for all involved in the transition from the current curriculum and teaching methods to NGSS (Pruitt, 2014; Wilson, 2013).

The challenges of modifying science content and instruction for an entire school, district and state is further complicated by the inconsistent state PD requirements. Each state's department of education establishes PD requirements for teacher certification renewal; however, those requirements lack specificity on PD content or delivery method (Olson et al., 2015). Even if a school district prescribes a specific PD program for its science teachers, each teacher would be learning about NGSS and applying standards to his or her existing set of knowledge and teaching practice in unique ways (Bowman, Jr. & Govett, 2015; Herrington & Daubenmire, 2016).

Transfer of Teacher Learning to Teaching Practice

Just as each PD participant develops an independent understanding of NGSS, each participant utilizes, or transfers, that PD training to classroom practice in different ways. Professional development designers and researchers have little understanding of how, or if, PD experiences translated to teaching practice (Hewson, 2007). Professional development designers and facilitators could offer an optimal program of instruction on a specific NGSS content area or instructional technique, but if there is no participant learning and no transfer to practice, the PD has not achieved a critical goal. Teacher learning and transfer from PD to the classroom has to be a significant component of PD design and evaluation (McDonald, 2011).

Transfer of learning, as defined by Dufresne, Mestre, Thaden-Koch, Gerace, and Leonard (2005), is "a complex dynamic process leading to the highly selective activation and application of knowledge in response to context" (pp. 155-156). If teachers are to transfer knowledge from the PD setting to classroom practice, there must be activation of the new or recently acquired knowledge and eventual application in the classroom.

Dufresne et al. (2005) focuses on the transfer process rather than a specific transfer goal or application. Transfer requires learners to activate knowledge composed of observations and beliefs in the process of evaluating context. Context and knowledge has to be compatible for any transfer of learning to proceed. Learning and transfer is influenced by language employed during the process. Dufresne et al. (2005) noted the “nonlinear and chaotic” (p, 161) nature of transfer. Transfer of learning occurs because the learners are searching for a remedy to a perceived situation; the learners’ perceptions of the situations are critical to transfer of learning.

In the context of changing standards and a movement to focus on student understanding of science and engineering practices, science teachers’ transfer of learning from PD experiences will be essential to modification of long-standing teaching practices. It is only through added attention to teacher knowledge, awareness of NGSS content and expectations, and exposure to innovative teaching practices that current science teachers will become proficient in teaching science according to the goals and expectations described in the NGSS.

Next Generation Science Standards Teaching Practice Research

The NGSS were released in 2013 (National Research Council, 2013a). Teachers and scholars began publishing material about the NGSS and its implementation even as the standards were being developed. The majority of scholarly publications currently available are policy statements (Bair & Bair, 2014; Januszyk, Miller, & Lee, 2016; Pruitt, 2014; Windschitl & Stroupe, 2017) or examples of science lesson modifications to fit NGSS (Concannon & Brown, 2017; Cunningham & Carlsen, 2014; Grooms, Enderle, & Sampson, 2015; Lewis, Baker, Watts, & Lang, 2014; Schiller, Melin, & Bair, 2016). Empirical research on NGSS teaching practice and implementation is available in recently published dissertations, although in relatively small numbers (Corvo, 2014; DiBenedetto, 2015; Kawasaki, 2015; Lazzaro, 2015; Lesinski-Roscoe, 2017) .

A 2018 search of the Proquest Dissertation and Theses database for empirical work published since 2012 and including the phrase "Next Generation Science Standards" in the document title or abstract and relating to secondary education produced twenty-two manuscripts. Of those twenty-two manuscripts, only three (DiBenedetto, 2015; Kawasaki, 2015; Lesinski-Roscoe, 2017) focused on teacher attitudes, perceptions, or teaching practices. No studies explored how current science teachers learn about NGSS and the associated teaching practices recommended for NGSS classroom teaching practices. DiBenedetto (2015) investigated science teacher thoughts, beliefs, attitudes, and values toward the nature of science learning. DiBenedetto's participants, five secondary science teachers, suggested four key ideas that were critical to their understanding of science learning: inquiry, involvement of teacher and student, respect for student voice, and changes in conceptual understanding (2015). Kawasaki (2015) interviewed five high school science teachers and two middle school science teachers and compared the participants' descriptions of science and engineering practices with observations of those same teachers utilizing the science and engineering practices with students. Kawasaki found varying degrees of alignment between the teachers' descriptions and their teaching practices. Lesinski-Roscoe (2017) explored scientific literacy in the context of academic reform as represented by the implementation of NGSS. Working with teachers from one high school, four science teachers and the building's literacy professional, Lesinski-Roscoe (2017) identified challenges faced by the participants as they worked to increase science literacy and suggested options for improved collaboration and communication between the classroom teachers and the literacy professional.

Two other dissertations, Corvo (2014) and Lazzaro (2014), presented research on NGSS instruction. Corvo (2014) examined his personal teaching practices as he designed and utilized NGSS-inspired units of study in the classroom. Following a cycle of unit design, classroom instruction, and reflection, Corvo (2014) noted a shift to a more student-centered teaching approach and an increase in efficiency and efficacy during the instructional design process. Lazzaro's (2014) study considered the broader education system during NGSS adoption and implementation. Participants — state education administrators, district administrators, and science teachers — were interviewed about the decision-making process during NGSS adoption and classroom implementation. Lazzaro (2014) found that participants who possessed a greater understanding of NGSS were stronger advocates for the adoption process; most participants did not have an understanding of the NGSS definition of "science practices".

A similar search for scholarly journal articles netted a small group of relevant articles. Haag and Megowan (2015) reported on a national survey of science teachers. Respondents were asked about teaching practices surrounding NGSS and engineering and teacher readiness for instruction with those practices. Study participants reported a need for engineering PD; high school teachers considered themselves better prepared than middle school teachers to implement NGSS (Haag & Megowan, 2015). Allen and Penuel (2015) conducted a multi-case study of three middle school teachers to explore their perceptions of coherence between PD, curriculum materials, and administrative guidance during a transition to NGSS. Participants identified the need for an understanding of the role of PD in the process of NGSS adoption and implementation (Allen & Penuel, 2015). Another national survey of K-12 teachers (Harris, Sithole, & Kibirige,

2017) indicated that teachers did not feel prepared to implement NGSS content or teaching practices. Teachers, especially those employed in poorly-resourced school districts, expressed concerns about a lack of knowledge, classroom materials, time, and administrative guidance (Harris et al., 2017).

Few of the available publications dedicated to NGSS provided in-depth study on teacher education (PD) or transfer of NGSS learning to classroom practice. Surveys (Haag & Megowan, 2015; Harris et al, 2017) suggested that current teachers do not feel prepared for the curriculum and pedagogical changes required with NGSS. Study findings (DiBenedetto, 2015; Kawasaki, 2015; Lazzaro, 2015; Lesinski-Roscoe, 2017) highlighted the effects of each teacher's perceptions and beliefs on the transfer of NGSS to classroom instruction. None of the publications specifically explored the experiences of veteran science teachers as states and school districts adopt NGSS.

Problem Statement

The Next Generation Science Standards are the K-12 science standards for Kansas and 19 other states (NGSS adoption map, 2014). All science teachers in those states are expected to teach science as it corresponds to NGSS content and science practices. NGSS incorporates student-centered teaching methods of inquiry, science and engineering practices, and scientific argumentation (National Research Council, 2013a; Reiser, 2013; Wilson, 2013) — an approach to teaching that is a marked contrast from the traditional didactic delivery methods preferred by many veteran high school science teachers (Banilower et al., 2013). Most of the available scholarly publications focused on a description of NGSS standards (Januszyk et al., 2016; Pruitt, 2014; Windschitl & Stroupe, 2017) or science lesson modifications (Grooms et al., 2015; Lewis et al., 2014; Cunningham & Carlsen, 2014). Little research is available on the experiences of science teachers as they learn about NGSS and transfer that learning and the standards into classroom practice; most of what has been published featured elementary school teachers (Hardré et al., 2018; Harlow, 2014; Van Duzor, 2011). Hardré et al. (2018), in a report about the incorporation of engineering practices in the science classroom, was one of the few studies that had high school teacher participants; this study only looked at one component of NGSS. No research has been located that explores the veteran high school science teachers' experiences as they learn about NGSS and transfer of that knowledge to classroom practice. This qualitative multi-case study provides information about the experiences of veteran high school science teachers as they learn about NGSS through formal PD, nonformal PD, and informal learning and transfer NGSS knowledge to teaching practice.

Purpose Statement

The majority of current science teachers are not prepared to teach science incorporating the three-dimensional approach prescribed by the NGSS authors and the NGSS. Any gaps in teacher content knowledge and pedagogy will need to be filled by PD; however, there are many questions about what will be transferred from those PD experiences to the classroom. The purpose of this study was to explore the formal, nonformal and informal ways that veteran high school science teachers describe their learning about NGSS and how those teachers transferred NGSS knowledge and the NGSS goals of inquiry, science and engineering practices, and scientific argumentation to the classroom.

Research Questions

The specific research questions for this study were:

1. How do veteran high school science teachers describe NGSS?

2. How do veteran high school science teachers describe their NGSS-focused experiences according to the classifications of formal, nonformal, and informal learning?
3. How do veteran high school science teachers transfer knowledge and modify teaching practices and science content as they incorporate NGSS specified inquiry, science and engineering practices, and scientific argumentation?

Research Design

As suggested in the problem statement, each teacher has a unique experience with his or her science teaching, exposure to NGSS and associated PD learning, and translation of that learning to the classroom and teaching practice (Bowman, Jr. & Govett, 2015; Herrington & Daubenmire, 2016). This research was designed to respect and draw attention to the differences and similarities among participants. This was a qualitative multi-case study with three participants. This type of study, a multiple case study, examines one issue with multiple cases to represent an array of experiences (Creswell, 2013). As with most qualitative case studies, generalization was not a goal for this study (deMarrais & Lapan, 2004).

Study Participants

The use of multiple participants allowed for comparison of experiences within and between the cases (Yin, 2009). Participant selection was criterion based (Creswell, 2013); a convenience sampling technique was used (deMarrais & Lapan, 2004). Study participants were "accessible, willing to provide information, and … shed light on a specific phenomenon or issue being explored" (Creswell, 2013, p. 147). For this study the participants were selected based on specific criteria: he or she was willing to participate in the research and had at least five years of experience teaching high school science. As this study focused on NGSS instruction and teaching practices, each participant was teaching a high school science class requiring the application of NGSS: life science, physical science — including physics or chemistry, or earth and space science.

Data

Qualitative data consisted of the following: semi-structured interviews with each participant, classroom observations, class documents, member checks, and researcher journal reflections. The data, once transcribed, were subjected to several cycles of coding (Saldaña, 2016) in an attempt to identify themes related to each participant's understanding of NGSS and teaching practices associated with NGSS. A conceptual framework of NGSS, learning delivery mode, and transfer of learning was used throughout data analysis (Dufresne et al., 2005), with attention to the participants' learning from formal PD, nonformal PD, and informal learning. This allowed an investigation into the manner in which each participant incorporated NGSS into his or her teaching and an exploration of factors influencing teaching practices.

Limitations

The limitations of this study were:

1. The participants were limited to one geographical area. The participants were within a 45-mile radius of the researcher's location to facilitate data collection.
2. This study was limited to high school, grades 9-12, science teachers. This was chosen to limit the experiences to a particular section of NGSS, the portion of standards pertaining to high school students.
3. The unit of analysis was the individual teacher. Attention was focused on the teacher's NGSS learning and transfer of learning to classroom practice. Other facets of

the participants' teaching and professional development were not addressed unless they were relevant to learning and knowledge surrounding implementation of NGSS.

4. Participants self-selected by volunteering to be part of this case study. The sample represented did not represent all high school science teachers.

5. Participants may have been prompted, on the basis of this study, to change teaching practices and modify teaching strategies.

Significance of Study

When making recommendations for NGSS implementation, states and districts were advised that "instruction will need to change substantially to support the NGSS" (National Research Council, 2015, p. 3). Recurring NGSS-specific professional development would be important for administrators and teachers. "Teachers will need time and support to transform their instruction" (National Research Council, 2015, p. 3). This study expanded the body of information about a specific group of teachers — the veteran teachers — and their experience learning about and implementing NGSS.

As states, school districts, and science departments make decisions about allocation of resources, information about the usefulness and value of PD will be beneficial. Each veteran science teacher has preferred learning strategies, PD delivery modes, and teaching practices. This study added to the discussion of those preferences as they apply to NGSS PD. The role of formal, nonformal, and informal learning opportunities in teacher learning was explored. Identifying teacher learning was constructive, but of greater interest was the transfer of NGSS knowledge to the classroom. This study expanded the discussion of teacher transfer of learning and knowledge from PD to the classroom for a specific population — the experienced science teacher as schools implement NGSS.

Definitions

Engineering practices – using skills to design or develop a process, product or system (Boesdorfer & Greenhalgh, 2014).

Formal professional development – For the purposes of this study, any learning opportunity with a specified curriculum that leads to educational credits, an academic certificate, or a degree.

Informal learning – Learning that occurs during or following routine, daily activities and occurs "outside the curricula provided by formal and non-formal institutions and programs" (Schugurensky, 2000, p. 2). This could include, but is not limited to, learning that results from professional reading, observations, peer collaboration, research, or reflection.

Inquiry-based instruction – Inquiry based instruction is any experience that allows the student to ask questions, design experiments, and analyze data (Rutherford & Ahlgren, 1990). Inquiry based activities may include student-guided research or inquiry-based laboratory experiments – any activity that allows students to have experiences comparable to those of a scientist (Fayer, Zalud, Baron, Anderson, & Duggan, 2011).

Knowledge (pedagogical content knowledge) – Knowledge of a subject matter and subject-specific teaching methods that facilitate learning for others (Shulman, 1986).

Nonformal professional development – Any professional development experience that has a structure or content specified by an organization (e.g., school, district, professional association) rather than the individual.

Professional development (PD) – For the purposes of this study, any professional educational experience; may include formal classes, or other trainings, nonformal conferences and workshops, or informal learning that occurs through collegial interactions, reflection, or other activities.

Scientific argument – written or verbal discourse that presents evidence, makes claims based on that evidence, and defends those conclusions (Grooms et al., 2015).

Transfer of learning – "a complex dynamic process leading to the highly selective activation and application of knowledge in response to context" (Dufresne et al., 2005, pp. 155-156).

Veteran secondary science teacher – For the purposes of this study, a veteran secondary science teacher will have at least five years' experience teaching in a grade 9-12 science classroom.

Chapter Summary

All K-12 science teachers are expected to incorporate inquiry, science and engineering practices, and scientific argumentation into their teaching practices. These skills may already be part of the veteran teacher's praxis but may not be used in the manner suggested by NGSS. Formal and nonformal professional development and informal learning should play a role in science teachers' learning, understanding, curriculum development and teaching skills practice as schools and districts implement NGSS; each teacher will determine what and how ideas are transferred from the PD experiences to the classroom. This multi-case study explored the NGSS learning and transfer of that learning to classroom practice by three veteran high school teachers.

Chapter 2: Literature Review

Introduction

The purpose of this study was to explore how veteran high school science teachers learned about the Next Generation Science Standards (NGSS) through formal, nonformal and informal learning experiences and how those teachers transferred NGSS knowledge and the NGSS goals of inquiry, science and engineering practices, and scientific argumentation into classroom practice. This chapter offers a summary of the literature relevant to this research. A thorough understanding of NGSS and its place in K-12 science education is necessary to understand the context of the veteran high school science teachers' education and experience. A summary of common science teacher PD opportunities supplies an overview of the types of learning activities the participants might experience. A review of adult learning with special attention to the adult learning theories or frameworks most often applied to teacher education provides the basis for understanding and interpreting the participants' comments and actions. The chapter concludes with a description of the transfer of learning.

Standards-Based Science Education

Science education has undergone a series of major revisions over the last three decades. The following publications and their role in science education will be addressed in the following section: *Science for All Americans*, *Benchmarks for Science Literacy*, *National Science Education Standards*, *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*, and *Next Generation Science Standards: For States, by States, Volume 1*. The section will conclude with an overview of the Next Generation Science Standards and some recommendations for teachers implementing those standards.

Science for All Americans

Efforts to integrate inquiry into science curricula date back to the 1960s. More recent efforts in science education reform can be traced to Project 2061 in *Science for All Americans* (Rutherford & Ahlgren, 1990). Citing global concerns that included "unchecked population growth in many parts of the world, acid rain, the shrinking of tropical rain forests" (1990, p. xiii), Rutherford and Ahlgren advocated for a scientifically literate population as a critical component to management and eventual resolution of the many challenges facing society. In addition to highlighting the foremost concerns with current science education, Rutherford and Ahlgren (1990) suggested major topics that were important to science literacy across the fields of science, mathematics, and technology. This idea of "crosscutting themes" (Rutherford & Ahlgren, 1990, p. xvii) persisted through several iterations of science education standards and is a key component of the current NGSS (National Research Council, 2013b).

Project 2061 was never envisioned to be a stand-alone document (Rutherford & Ahlgren, 1990). The set of ideas presented in *Science for All Americans* was always intended to be the introduction to a renovation of science education and the start of a movement towards a scientifically literate society. Project 2061 organizers anticipated, published, and currently maintain tools for teachers, districts, and curriculum developers that included resource databases and curriculum models (American Association for the Advancement of Science, 2018; Rutherford & Ahlgren, 1990). Perhaps the most significant document to follow *Science for All Americans* was the *Benchmarks for Science Literacy* (Anderson, Druger, James, & Katz, 1998; Rutherford & Ahlgren, 1990).

Benchmarks for Science Literacy

Published in 1993, *Benchmarks for Science Literacy* (*Benchmarks*) (American Association for the Advancement of Science) was an attempt to translate the vision of science education that was presented in *Science for All Americans* into a set of standards or benchmarks that represented a common core of science learning expected of all K-12 students. The *Benchmarks*, like subsequent documents, did not present a science curriculum; the *Benchmarks* presented a series of targets, standards, or goals that local curriculum designers could use to develop their own materials (Ahlgren & Rutherford, 1993; American Association for the Advancement of Science, 1993).

Many difficult decisions were made during the development and writing of the *Benchmarks*. The breadth of required science content had already been restricted by the *Science for All Americans* authors, but there was still need for additional refinement. Once the critical science areas were identified, content and learning expectations had to be distributed across the K-12 academic education. This distribution was complicated by the knowledge that science learning was not linear or evenly distributed and all science concepts were not appropriate for all grade levels (Ahlgren, 1993). The *Benchmarks* publication broke science instruction goals into four segments: expectations for students by the end of grade 2, by the end of grade 5, by the end of grade 8, and by the end of grade 12 (American Association for the Advancement of Science, 1993). The *Benchmarks* included efforts to weave together connections between science, mathematics, and technology. With the assistance of teachers, students should "come to understand science as a dynamic, cross-connected enterprise involving mathematics and technology, as well as the natural and social sciences" (Ahlgren & Rutherford, 1993, p. 20). This was a dramatic shift for the K-12 education system, particularly for those in the elementary classrooms. Teachers of science, regardless of grade level, were challenged to incorporate mathematics and technology into science curriculum and to guide students to thinking and learning like a scientist (Ahlgren & Rutherford, 1993; American Association for the Advancement of Science, 1993); both ideas were vastly different than most existing science curricula.

The *Benchmarks* presented a cohesive and comprehensive set of science education goals for the K-12 system. Following the mandate of a scientifically literate populace, these goals were minimum expectations and applied to all students (American Association for the Advancement of Science, 1993). Material in the *Benchmarks* explained the nature and level of understanding and application expected at a particular grade level and, where possible, suggested "appropriate kinds of instruction" (Ahlgren, 1993, p. 48). Even with these suggestions, the *Benchmarks* was written as a guideline; curriculum and application were left to teachers and local curriculum developers with no weight of enforcement (American Association for the Advancement of Science, 1993).

National Science Education Standards

The *Benchmarks* was a critical component in a national vision of science education but was soon displaced by another document intended to guide the nation's educators. The *Benchmarks* provided guidelines but did not bear the weight and influence of national standards While not enforceable, national standards could and did often supply a national vision for the field (Anderson et al., 1998; Raizen, 1997). Although states were encouraged to use the *Benchmarks* to develop state standards, they were not required to do so. Poor student performance, increased understanding of how science was learned, and advances in technology contributed to the need for an update and expansion of the *Benchmarks* into a set of national science standards (Raizen, 1997) with the reputation of a nationally recognized educational organization to support it.

Following the impetus of *Science for All Americans* and *Benchmarks for Science Literacy*, along with efforts by other national science organizations, the National Research Council began the development of a set of national science standards in 1991 (Collins, 1997; National Research Council, 1996). The new standards would eventually be known formally as the National Science Education Standards (NSES). The NSES was built on the foundation provided by *Science for All Americans* and the contemporary concerns of science literacy and the growing influence of science on society.

The NSES attempted to address all aspects of science education. Standards were included for science teaching, professional development of science teachers, assessments, science content, science education programs, and science education systems (Collins, 1997; National Research Council, 1996). The NSES - like its predecessor, the *Benchmarks*, and its successor, NGSS - did not provide a curriculum, but offered a set of standards or objectives for the science education community (Ahlgren, 1993; Anderson et al., 1998; Roseman & Koppal, 2008). Using the NSES, states created their own standards and state assessments (National Research Council, 2013b). Districts, science departments, and individual teachers made decisions about the teaching methods and materials for a given set of content and grade level (Anderson et al., 1998; Bybee & Champagne, 2000). NSES continued the idea that science was for all students and the standards should apply equally to all (Collins, 1997; National Research Council, 1996); science education and science literacy was an important part of the K-12 education.

The NSES continued the shift away from knowledge of a specific set of facts and towards major science themes such as evidence, models, and explanations (Bybee & Champagne, 2000; Collins, 1997; National Research Council, 1996). The standards recommended an integration of science concepts during instruction and a development of knowledge through inquiry learning experiences. NSES incorporated specific standards for professional development (PD) for science teachers as well as standards for the school and educational system to insure the necessary resources for NSES implementation at the classroom level (National Research Council, 1996). These latter components – PD and school and educational system standards – were not included in the *Benchmarks* (American Association for the Advancement of Science, 1993) or the NGSS (National Research Council, 2013a, 2013b).

In response to stakeholder concerns, the NSES addressed all areas of science instruction. States and local districts were struggling with science instruction; explicit standards contained in NSES addressed PD and assessment (Bybee & Champagne, 2000; Demers, 2000). With the implementation of NSES, teachers were expected to make changes in curriculum, teaching methods, and assessment techniques; consistent and regular support was required from all levels – department, building, district, and state (Bybee & Champagne, 2000). The NSES incorporated specific standards for science teaching, PD for current teachers, science education programs, and science education systems (National Research Council, 1996).

The NSES provided a national vision of science education. States were encouraged to adopt and utilize NSES to inform their own state standards and assessments. NSES served the science education community as a valuable resource for over ten years. In 2010, following similar initiatives in mathematics and English/language arts with the beginning of the development of the Common Core Standards (Common Core State Standards Initiative, 2017), science educators looked to update the NSES (National Research Council, 2013b; Roseman & Koppal, 2008). Advances in science, technology, and educational research contributed to the need for a revision or replacement of the existing set of educational expectations. State standards and corresponding assessments were not serving the education community well. “Many students are being evaluated with high-stakes state tests that are aligned to fundamentally weak learning goals” (Roseman & Koppal, 2008, p. 109). These issues, combined with attention from many within the science education community, initiated the most recent revision of the national science education standards.

A Framework for K-12 Science Education

As with the development of the NSES, a national effort was led by the National Research Council with input from the American Association for the Advancement of Science, Rutherford and Ahlgren (authors of *Science for All Americans*), and the National Science Teachers Association. The outcome of these efforts was *A Framework for K-12 Science Education* (National Research Council, 2012), subsequently known as the *Framework*. Constructed by prominent scientists and educators, the *Framework* was not intended to be a set of national science standards, but rather as a guideline for identifying the most important ideas, skills, and practices required of all K-12 students. The *Framework* established a scaffolding of knowledge, understanding and skill designed to introduce ideas at an earlier age in a simpler fashion; the complexity in understanding would increase as students progressed through their K-12 science education (National Research Council, 2012).

The *Framework* made substantial updates to NSES. The emphasis on inquiry was still incorporated in the *Framework*, but the understanding and practice of inquiry was modified to reflect the academic research accumulated in the interim (National Research Council, 2012).

The other major change in the *Framework* was the inclusion of an emphasis on science and engineering practices (Keller & Pearson, 2012; Sneider, 2012). The *Framework* established goals for all students; goals that allowed students to "continually build on and revise their knowledge and abilities" and develop "a more scientifically based and coherent view of the sciences and engineering" (National Research Council, 2012, p. 11). Following the scaffolding introduced in the NSES, the *Framework* accentuated the structure of early introduction of concepts with a subsequent increase in idea complexity and expectation of student responsibility for developing knowledge. This knowledge development would be facilitated by students' experiencing science and engineering in a practical, hands-on manner, rather than traditional didactic delivery of information. (National Research Council, 2013b; Sneider, 2012).

Next Generation Science Standards: For States, by States

With the *Framework* as a guide, Achieve, Inc. — "an independent, nonpartisan, nonprofit education reform organization" (Achieve, Inc., 2017) — was contracted to write the Next Generation Science Standards (NGSS) (National Research Council, 2013b). Like the NSES, the NGSS was written to be "a vision for science education in classrooms throughout our nation" (National Research Council, 2013b, p. iv). As of 2019, 20 states, including Kansas, have adopted NGSS as their state science standards and are implementing them in school districts (NGSS adoption map, 2014). NGSS, like its precursors, the *Benchmarks* and NSES, was not designed to be a curriculum or to provide districts and schools with specified sets of lessons and learning experiences that must be employed in every classroom. The NSES, the *Framework*, and NGSS were intended to offer a structure for curriculum and textbook authors to build science content and instruction on (National Research Council, 2013b; Pruitt, 2014). Districts, schools, and classroom teachers are expected to utilize current and supplemental resources to deliver instruction and learning opportunities to meet the standards outlined in the NGSS.

Much of the structure and substance of the *Framework* is visible in the NGSS, a feature that was deliberate. Content was streamlined, narrowed to topics considered critical by both the *Framework* and NGSS publications (Bowman, Jr. & Govett, 2015; National Research Council, 2012, 2013a, 2013b). The amount of science topics was decreased to allow for "deeper understanding and application of content" (National Research Council, 2013a, p. xiii). Students are expected to build upon pre-existing knowledge and increase understanding and complexity throughout the K-12 science education experience. Science concepts are integrated across grade levels. Three dimensions — disciplinary core ideas, crosscutting concepts, and science and engineering practices — influence every tier of the K-12 science experience. Underlying every topic and grade level is the opportunity to utilize science practices, specifically inquiry, science and engineering practices, and scientific argumentation (National Research Council, 2013b; Reiser, 2013; Sneider, 2012). The emphasis on inquiry is not new to science standards; the value placed on engineering practice and scientific argumentation for all students is novel and a source of challenge for many science teachers (Banilower et al., 2013; Cunningham & Carlsen, 2014; Reiser, 2013).

The text, *Next Generation Science Standards: For States, by States, Volume 1* (National Research Council, 2013a), includes the K-12 science standards developed during a three-year-long process. The standards describe the performance expectation for each included science topic divided by grade level subset. These standards address student performance, not teaching practice, curriculum materials, or assessment method (National Research Council, 2013b). Those issues, and many others, are addressed in supplementary publications. *Next Generation Science*

Standards: For States, by States, Volume 2 (National Research Council, 2013b) includes essays explaining the choices made during the design process, possible course mapping for middle and high school science programs, and connections between NGSS and Common Core State Standards. The *Guide to Implementing the Next Generation Science Standards* (National Research Council, 2015) fills in the omitted portions from the NSES – science teacher PD and school and system science education systems. The National Research Council provides guidance on preparation of NGSS-appropriate assessments in *Developing Assessments for the Next Generation Science Standards* (National Research Council, 2014). As a group, these documents suggest how states, school districts, science departments, and classroom teachers can adopt and implement NGSS.

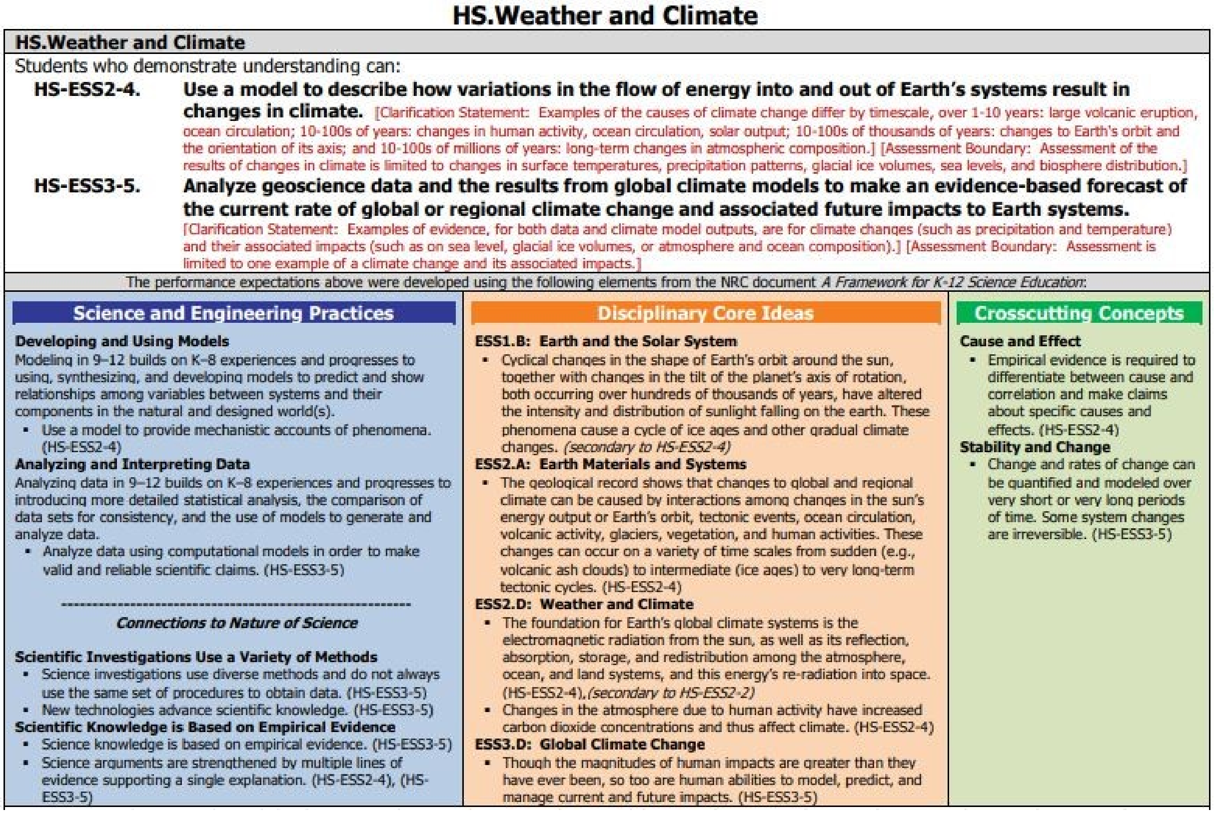
Next Generation Science Standards Structure

The NGSS divide science content into four major areas: life science, physical science, earth and space science, and engineering, technology, and applications of science (National Research Council, 2013b). The content is further broken down, using guidelines published in *A Framework for K-12 Science Education*, into discrete standards for specific grade levels. The elementary grades, K-5, has a set of standards for each grade; grades 6-8, middle school, has a set of standards, and grades 9-12, high school, receives the final set of standards, completing the vision of science education (National Research Council, 2013a). The division of content is deliberate, "allowing for a dynamic process of building knowledge throughout a student's entire K-12 science education" (National Research Council, 2013a, p. xiii). Each standard, regardless of grade level, is divided into several performance expectations (PE) that provide the assessable goals for science instruction (National Research Council, 2013b; Pruitt, 2014).

The Next Generation Science Standards incorporate disciplinary core ideas (DCI), crosscutting concepts (CC), and science and engineering practices (SEP) throughout the standards (Duncan & Cavera, 2015; National Research Council, 2013b). The DCIs are the major concepts in each of the "four major domains: the physical science; the life sciences; the earth and space sciences; and engineering, technology, and applications of science" (National Research Council, 2013a, p. xvi). Seven crosscutting concepts provide "a set of lenses that can be used to explore and explain phenomena" (Duncan & Cavera, 2015, p. 53). These crosscutting concepts include the following: patterns; cause and effect; scale, proportion, and quantity; systems and system models; energy and matter in systems; structure and function; and stability and change of systems (National Research Council, 2013a, p. xx). There are eight science and engineering practices identified as common components to all science:

1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6: Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information (National Research Council, 2013a, p. xx)

The standards deliberately overlap and intermingle DCI, CC and SEP. Figure 1 provides an example of the interwoven nature of the DCI, SEP, and CC in the High School Earth and Space Science topic: Weather and Climate. The performance expectations (PE) describe the specific tasks or skills that correspond to the standard. The DCI information is usually listed with a single standard; the SEP and CC, by their nature, appear in multiple standards (Duncan & Cavera, 2015; National Research Council, 2013b). For this Weather and Climate topic, the four DCI are listed in the center column; SEP and CC are on either side. The DCI includes explanations of the material students should learn, SEP provides critical practices that are applicable to those ideas, and CC illustrates the inter-related nature of each standard. The inclusion of SEP, DCI, and CC reinforces the NGSS vision of science as a way of thinking and a complex set of knowledge, not a list of facts (Duncan & Cavera, 2015; National Research Council, 2013b; Pruitt, 2014).



HS.Weather and Climate

HS.Weather and Climate

Students who demonstrate understanding can:

HS-ESS2-4. **Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.** [Clarification Statement: Examples of the causes of climate change differ by timescale, over 1-10 years: large volcanic eruption, ocean circulation; 10-100s of years: changes in human activity, ocean circulation, solar output; 10-100s of thousands of years: changes to Earth's orbit and the orientation of its axis; and 10-100s of millions of years: long-term changes in atmospheric composition.] [Assessment Boundary: Assessment of the results of changes in climate is limited to changes in surface temperatures, precipitation patterns, glacial ice volumes, sea levels, and biosphere distribution.]

HS-ESS3-5. **Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.** [Clarification Statement: Examples of evidence, for both data and climate model outputs, are for climate changes (such as precipitation and temperature) and their associated impacts (such as on sea level, glacial ice volumes, or atmosphere and ocean composition).] [Assessment Boundary: Assessment is limited to one example of a climate change and its associated impacts.]

The performance expectations above were 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 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s).

- Use a model to provide mechanistic accounts of phenomena. (HS-ESS2-4)

Analyzing and Interpreting Data

Analyzing data in 9–12 builds on K–8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.

- Analyze data using computational models in order to make valid and reliable scientific claims. (HS-ESS3-5)

Connections to Nature of Science

Scientific Investigations Use a Variety of Methods

- Science investigations use diverse methods and do not always use the same set of procedures to obtain data. (HS-ESS3-5)
- New technologies advance scientific knowledge. (HS-ESS3-5)

Scientific Knowledge is Based on Empirical Evidence

- Science knowledge is based on empirical evidence. (HS-ESS3-5)
- Science arguments are strengthened by multiple lines of evidence supporting a single explanation. (HS-ESS2-4), (HS-ESS3-5)

Disciplinary Core Ideas

ESS1.B: Earth and the Solar System

- Cyclical changes in the shape of Earth's orbit around the sun, together with changes in the tilt of the planet's axis of rotation, both occurring over hundreds of thousands of years, have altered the intensity and distribution of sunlight falling on the earth. These phenomena cause a cycle of ice ages and other gradual climate changes. *(secondary to HS-ESS2-4)*

ESS2.A: Earth Materials and Systems

- The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long-term tectonic cycles. (HS-ESS2-4)

ESS2.D: Weather and Climate

- The foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space. (HS-ESS2-4),*(secondary to HS-ESS2-2)*
- Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate. (HS-ESS2-4)

ESS3.D: Global Climate Change

- Though the magnitudes of human impacts are greater than they have ever been, so too are human abilities to model, predict, and manage current and future impacts. (HS-ESS3-5)

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-ESS2-4)

Stability and Change

- Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. (HS-ESS3-5)

Figure 1. NGSS HS. Weather and Climate. Reprinted from Achieve, 2016.

Teaching with Next Generation Science Standards

Next Generation Science Standards (NGSS) does not simply replace or update the pre-existing science standards. NGSS, through the integration of science content and engineering practices, requires specific ways of teaching science as well as content knowledge many teachers may not possess (Banilower et al., 2013; Reiser, 2013; Wilson, 2013). This presents challenges to practicing teachers. Some traditional science content is excluded with NGSS (Bowman, Jr. &

Govett, 2015) even as teachers are required to incorporate scientific argument, learning through inquiry, and science and engineering practices in the curriculum (National Research Council, 2015). An online survey of 214 K-12 teachers in 16 states suggested that these teachers did not feel prepared "to fuse the proposed changes in standards with the current curricula and their teaching plans" (Harris et al., 2017, p. 54). That blending of existing science knowledge and teaching practice with NGSS's three dimensions of SEP, DCI, and CC will be critical for teacher success and student learning as states adopt NGSS (Duncan & Cavera, 2015).

Science skills — inquiry, science and engineering practices, and scientific argumentation — are key elements of the NGSS and all present challenges for science teachers. Learning and teaching through inquiry allows students to design experiments, explore science, manage data, and draw conclusions (National Research Council, 2000). Students experience problem solving through science and engineering activities that support science learning (Cunningham & Carlsen, 2014). Scientific argumentation, defending conclusions based on data and logic, provides students the opportunity to learn science while acting as a scientist (Colson & Colson, 2016). These three practices complement one another and support student knowledge construction; they are an integral part of learning as defined within NGSS and need to be incorporated in instruction and assessment (Bowman, Jr. & Govett, 2015; National Research Council, 2015; Pruitt, 2014; Reiser, 2013). All K-12 science teachers will have to incorporate inquiry, science and engineering practices, and scientific argumentation as part of all aspects of the science curriculum.

The classroom teacher has the greatest responsibility to translate NGSS into practice in the classroom. "The success of NGSS in K-12 education reform mostly depends on the teacher's ability to translate the standards into practical lesson plans and classroom activities coupled with the development of sound pedagogical skills" (Harris et al., 2017, p. 56). Teachers need a comprehensive understanding of the standards and expectations of NGSS instruction as they planned and executed science lessons.

The NGSS changes encompasses content, instruction, science practices, and assessments. Science teacher educators and science consultants have proposed several ideas to enhance student learning and meet the teaching expectations of NGSS that have been presented in the literature. NGSS relies upon complementary performance expectations (PE) that "depict what students must do to show proficiency in science" (National Research Council, 2013a, p. xxi). Krajcik, Codere, Dahsah, Bayer and Mun (2014), a group of science teacher educators and science teachers, recommended that current teachers group corresponding PEs within a lesson or unit of instruction. This technique should allow for more efficient use of instructional resources and facilitate student learning. Natural scientific phenoma are often used as a common starting point for science instruction and facilitating student explanation building (Reiser, 2013). Teachers are encouraged to structure units and lessons around a single scientific phenomenon (National Research Council, 2015; Reiser, 2013). Teachers and students can then return to that phenomenon throughout the unit to apply new information and refine scientific ideas. Another strategy proposed by science teacher educators (Peacock, Evans, & Melville, 2016) addresses the challenges of inquiry, science and engineering practices, and scientific argumentation. When teachers are planning lessons during early phases of NGSS implementation, they should concentrate on one area of interest or concern within NGSS — for instance, inquiry — and modify existing lessons or adopt alternative lessons that featured this content or learning experience (Peacock et al., 2016). This focuses attention on one area of NGSS emphasis at a time rather than attempting to incorporate all aspects of NGSS simultaneously.

Lesson planning contributes to the success of NGSS implementation and student learning; teaching practice also plays a critical role. Teachers must be mindful of the instructional strategies employed. Rather than relying upon traditional teaching methods, teachers should select instructional strategies that have shown to be “efficient and effective” (Grooms et al., 2015, p. 47) for quality science instruction. This is especially true for teachers unfamiliar with some of the science and engineering practices included in NGSS. Teachers should encourage students to higher levels of thinking and understanding that includes explanations and logical use of evidence to support student ideas (Krajcik et al., 2014). Pellegrino, Wilson, Koenig, and Beatty, authors of *Developing Assessments for the Next Generation Science Standards* (2014) recommended that assessments should require more than simple memorization and fact-based responses. Students should be expected to incorporate inquiry, science and engineering practices, and scientific argumentation on a variety of assessments within the NGSS classroom.

Science teaching with the NGSS is more than simple modification of content to fit the standards; it is more than inclusion of engineering projects or inquiry laboratory experiments. Teachers must find ways to foster student development of science knowledge rather than the traditional learning of facts. Many current teachers will need additional support and training to meet these expectations as schools adopt and implement NGSS.

Summary

Driven by advances in educational research and improving access to technology, the vision of science education has undergone a series of revisions beginning with the *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993) to the current standards: the Next Generation Science Standards (National Research Council, 2013a).

With each subsequent document or set of standards the general goal has remained the same: to teach students to think and learn like scientists (Ahlgren & Rutherford, 1993; National Research Council, 1996, 2012, 2013a). The current standards, NGSS, feature streamlined science content influenced by disciplinary core ideas, crosscutting concepts, and science and engineering practices (National Research Council, 2013a). All levels of the K-12 education system, teachers, building administrators, district officials, and state-level education officials, will need professional development during the adoption and implementation of NGSS (National Research Council, 2013b; Pruitt, 2014).

Science Teacher Professional Development

National, state, and local science standards influence science teacher education and science teacher continuing education or professional development (PD); as NGSS influences those standards, PD is becoming even more significant. As science standards are updated or changed, PD and other learning opportunities provide the venue for practicing teachers to explore incoming curriculum requirements and teaching practices (Lawless & Pellegrino, 2007). Professional development can be defined as the "long-term process extending from teacher education at university to in-service training at the workplace" (Richter, Kunter, Klusmann, Lüdtke, & Baumert, 2011, p. 116). The inclusion of "in-service training" in Richter et al.'s definition of PD may be misleading. The National Research Council (2000) recognizes that many of the settings for teacher learning are not in a structured setting, something that is often implied in the phrase "in-service training". Teachers learn from their own teaching practice, from collaboration and counseling with peers, and from personal experiences outside of the school setting (National Research Council, 2000). All of these occur in addition to the more deliberate and formal "in-service" trainings available to most teachers. Regardless of the format

— formal, nonformal, or informal — PD and professional learning is an important part of every science teacher's preparation for teaching with NGSS.

The following discussion of PD will include a description of professional development and professional learning; a list of typical characteristics of teacher-learners; a summary of best practices for science teacher PD; an overview of PD experiences and professional learning available to practicing teachers; and specific suggestions for NGSS-oriented PD.

Professional Development or Professional Learning

The label "professional development" encompasses the formal and nonformal learning opportunities available to practicing science teachers. Some education advocates would have the teacher education community transition from the phrase "professional development" to "professional learning" (Schugurensky, 2000; Smith & Lindsay, 2016). Traditional PD is those formal and nonformal learning opportunities; traditional PD is frequently prescriptive and required, often impersonal or inflexible (Herrington & Daubenmire, 2016). The phrase "professional learning" shifts attention from the traditional delivery of PD and allows recognition of "the central role that teachers play in the learning process" (Smith & Lindsay, 2016, p. 245). This adjustment also acknowledges the critical nature of the informal experiences — hallway collaborations, professional reading — on teacher learning (teacher growth).

Teachers as Learners

Practicing teachers, as adult learners, are not passive recipients of instruction. Teacher PD experiences should be designed to allow the individual participant to take responsibility for his or her own learning (Luft & Hewson, 2014). PD developers and administrators must acknowledge the critical role of the learner in any PD offering. The learners ultimately determine the nature and direction of any instruction (Bowman, Jr. & Govett, 2015; Herrington

& Daubenmire, 2016). Success of PD programs cannot be defined by teacher compliance with the goals of that PD program (Smith & Lindsay, 2016). Teacher training and education can only be considered productive if the learners find value in the instruction and utilize the PD experiences to inform subsequent teaching practice.

Teachers, and other adult learners, will "organise the learning process and determine their learning goals and strategies independently" (Richter et al., 2011, p. 117). Each teacher's individual circumstances influence the choices and value placed on PD learning opportunities. Many other factors affect teacher learning: age or career progression (Schulz & Roßnagel, 2010), PD delivery method (Borko, 2004), and departmental or administrative influences (Opfer & Pedder, 2011). Each of these factors, and others, play a role in individual learning and influences how much learning each teacher transfers from PD to teaching practice.

Professional Development Best Practices

Science teacher PD and learning can be situated in many formats and venues – formal (college courses, research experiences for teachers); nonformal (workshops, professional conferences); or informal (hallway collaborations, professional reading, classroom observations) (Borko, 2004; Desimone, 2009; Bransford, Brown, & Cocking, 2000). Training can be delivered individually, in small groups, or in a large class setting; PD can be face-to-face or in a virtual setting. Regardless of the format or delivery method, several key elements of PD have been identified: PD should be content-specific, offer active learning experiences, be coherent with current standards and local systems, and sustained (Desimone, 2009; Garet et al., 2001; Wilson, 2013). Other researchers (Beerer & Bodzin, 2004; Capps, Crawford, & Constas, 2012; Kazempour, 2009) emphasize the need for continuous individual and collaborative reflection for

PD participants. Each of these factors influence, to some extent, the participants' learning and transfer of learning to teaching practice.

Practicing teachers have limited resources, including time, to invest in PD experiences. Professional development must be relevant to the classroom or teaching experience (Garet et al., 2001; Lustick, 2011). Professional development that incorporates active learning and collaboration brings greater changes to teacher practice (Crippen, Biesinger, & Ebert, 2010; Jones & Dexter, 2014; van Driel et al., 2012) than PD that does not include collaboration opportunities. Coherence of PD with both the personal and professional setting is essential to efficacy (Garet et al., 2001; Herrington & Daubenmire, 2016). Professional development must be sustained and persist long enough to influence teacher belief and practice. While no definitive time requirement has been identified, PD duration was found to be a significant factor in effective PD programs (Bair & Bair, 2014; Garet et al. 2001; Herrington & Daubenmire, 2016; Lewis et al., 2014; Supovitz & Turner, 2000).

Professional development that offers these features — content-specific, active, coherent, sustained, and collaborative — has been shown to support teacher learning. Those qualities can be found in many PD formats — formal PD, nonformal PD, and informal learning — and venues — higher education courses, workshops, and routine activities.

Formal Professional Development

Formal learning opportunities occur with structured learning environments and a specified curriculum (Feiman-Nemser, 2001). Merriam et al. (2007) narrows formal PD more by suggesting that the learning experiences usually lead to educational credits, an academic certificate, or a degree. Differentiating between formal and nonformal learning opportunities can be challenging. Smaller (2005) does not make a distinction between formal and nonformal learning, including all structured teacher education under one heading. With the continued expansion of continuing education beyond the expanses of the traditional collegiate environment and the increased frequency of less formal learning opportunities it can be helpful to separate the more structured and institution-orchestrated training experiences in a separate category from the briefer, needs-based learning activities that occur in nonformal experiences.

Practicing science teachers who want or need longer PD programs have several options. College courses are available that focus on science content or pedagogy (Blasie & Palladino, 2005; Vick, 2017). Another option, research experiences for teachers (RET), affords practicing teachers the opportunity to spend several weeks or longer working with scientists on field research (Blanchard, Southerland, & Granger, 2009; Peters-Burton, Merz, Ramirez, & Saroughi, 2015). Both of these types of PD opportunities fulfill the duration requirement that is not usually met by nonformal or informal learning opportunities and offers the practicing teacher additional attention on science practices or content knowledge.

Teachers are often attracted to college courses that can serve multiple needs including career advancement and classroom practice influence. Blasie and Palladino (2005) studied a cohort of inservice teachers enrolled in a master's program for science teachers. Instructional material was content-specific. Participants had active learning requirements, and the instruction was sustained: fulfilling most of the suggested components of quality PD (Garet et al., 2001; Wilson, 2013). This program afforded the participants many opportunities for collaboration (van Driel et al., 2012), as the cohort moved through the required courses as a group. Despite all the positive elements to the program design, researchers did not see any measurable or obvious changes to teaching practice during or following this program (Blasie & Palladino, 2005). The program was found to have "assisted teachers in developing professional identities as science teachers and encouraged a disposition about their own teaching" (Blasie & Palladino, 2005, p. 570). The participating teachers did not make any measurable changes in classroom practice, but they did realize benefits in the growth of their identity and understanding of their personal teaching beliefs.

Teaching methods courses are a typical part of pre-service teacher education programs; they can also provide learning opportunities for the experienced teachers serving as mentors. Vick (2017) described one pre-service methods course for K-6 teachers. This university course utilized an alternate location, a local elementary school, for class meetings. Pre-service teachers spent time observing current teachers as they taught science lessons. As the course progressed the pre-service teachers collaborated with the mentor teachers, eventually co-teaching science lessons. There were obvious benefits for the pre-service teachers as they learned about NGSS and the three-dimensional nature of lesson planning and implementation (Vick, 2017). What was not anticipated was the findings about the mentor teachers' experiences. The inservice teachers, the mentors, reported valuable learning from the course. Several mentors noted a growth in their role as a facilitator in the science classroom, shifting from a previous disposition to information presentation. The inservice teachers had frequent conversations about teaching and learning, both as it applied to their classroom and to other teachers (Vick, 2017). A formal learning experience for the pre-service teachers contributed in unexpected ways to the learning of the experienced mentor teachers.

Another type of formal learning opportunity, research experiences for teachers (RET), offers practicing teachers the opportunity to be a scientist. Some programs afford teachers the opportunity to join scientists on an active research project (Blanchard et al., 2009), others require the teacher-participants to design and conduct a research study (Peters-Burton et al., 2015).

These programs are time-intensive, potentially expensive, and limited to a small number of participants. Despite those challenges, there is strong support for teachers gaining practical experience with scientific research that could transfer to improved science teaching (Pop, Dixon, & Grove, 2010).

Blanchard et al. (2009) described a six-week-long summer marine ecology research project. Researchers assessed the participants' usage of inquiry before and after the RET experience. Participants' use of inquiry in the classroom increased, and the level of inquiry utilized was more challenging for the participants' students after the teachers' participation in the RET (Blanchard et al., 2009). Researchers noted a correlation between the participants' usage of inquiry and the motivation to learn about inquiry. Teachers who specifically expressed a desire to learn about inquiry demonstrated a greater increase in their usage of inquiry when compared with the other RET participants (Blanchard et al., 2009). Prolonged immersion in RET experiences was beneficial to the study participants' teaching practices; these benefits were greater for motivated participants.

Other RET programs require participants to design and conduct their own research, rather than joining an in-progress study. Researchers compared inquiry perceptions of participants before and after a one year-long apprenticeship-aided RET (Peters-Burton et al., 2015). Participants were required to develop and conduct a study, with the oversight of experienced researchers. Following the study, participants had changed their perceptions of scientific research and inquiry. Participants noted an increase in self-efficacy as a result of the experience (Peters-Burton et al., 2015).

These examples of formal PD were structured, longer in duration, and sponsored by academic institutions. Other PD opportunities have a structure or content specified by an outside organization, state-mandated PD or university-provided training, but lack the additional features of sustained education that is part of a college credit program. These learning opportunities can be classified as nonformal learning.

Nonformal Professional Development

Most nonformal learning is focused on immediate needs of the local population (Taylor, 2006), short-term (Schugurensky, 2000) and voluntary (Bullock, 2014; Schugurensky, 2000); although the voluntary aspect of the description does not apply to some of the PD teachers experience. Nonformal professional development can be mandated by administration or selected by the teacher participants (Farrell, 2013). The mandated, or top-down, PD may be less successful as it “implicitly, and sometimes explicitly, devalues the individual learner” (Roseler & Dentzau, 2013, p. 620). Bullock (2014) and Taylor (2006) noted the less formal structure of the relationship between the participants of nonformal learning; the hierarchy of the instructor-student relationship that is part of most formal learning is often not present in nonformal learning experiences.

Much of the PD available to and utilized by practicing teachers, regardless of the content area, is delivered in short timeframes, frequently in a workshop setting. These nonformal learning experiences, while common, have limited success (Yezierski & Herrington, 2011) and often have little or no impact on subsequent teacher practice (Herrington & Daubenmire, 2016). Kennedy (2016) suggested that mandatory PD offerings might meet with greater learner resistance because the practicing teachers “have already developed their practice” and “any new idea offered by PD not merely adoption but also *abandonment* of a prior approach” (p. 3-4). In one report of PD (Holloway, Jr., 2015), participants expressed no interest in attending more workshops if the only outcome was a collection of documents delivered by the facilitator. This group of teachers desired an active learning environment that would allow them to collaborate with other attendees to prepare products for immediate application to the classroom. Duration or length of PD seems to be very important for participants' perception of value. Several studies (Blank, De las Alas, & Smith, 2008; Herrington & Daubenmire, 2016; van Driel et al., 2012) suggested that PD lasting less than 50-80 hours was ineffective and had little to no impact on teacher beliefs or teaching practices. Despite those discouraging findings, examples of nonformal, short-term PD are widespread, and many reports suggest the teachers are finding value in the experiences.

A three-year-long cycle of quarterly day-long NGSS workshops for one school district's middle school science teachers was evaluated by researchers (McGee & Nutakki, 2017). Teachers volunteered or were required by administration to participate in the program. Each quarter's workshop covered NGSS content and learning experiences immediately transferable to the classroom. Following the end of the program, all teachers in the district were asked to complete a survey that contained questions about teacher PD utilization and changes in teaching practice (McGee & Nutakki, 2017). Teachers who participated in the NGSS workshop program reported that the workshop series had a direct impact on teaching practice. There was also an indirect impact on other teachers in the same building with the workshop participants; those teachers noted changes in their own teaching practice following informal learning with the workshop participants (McGee & Nutakki, 2017). Although each of these workshops was relatively short – one day - the participants felt they had made changes in teaching practice that were directly attributable to the PD program.

A bonus to the PD program described by McGee and Nutakki (2017) was the additional influence on teachers who were not actively involved in the PD workshop series. The participating teachers shared their PD experiences with colleagues. That use of local experts, master teachers or teacher mentors, is common in nonformal PD (Taylor, 2006). These local experts can play critical roles in expanding NGSS knowledge and teaching practice (Bills, Kulkarni, & Hart, 2017; Reiser et al., 2017).

Local, experienced teachers played a critical role in another PD program. Quarterly workshops were held in one school building with elementary school teachers from buildings across the school district and a guest teacher (Bills et al., 2017). The group met in an elementary classroom with a group of students. The guest teacher, a master teacher, facilitated a science lesson for the students and the other teachers. Immediately after the science lesson the teachers met with the master teacher for several hours to discuss what happened during the lesson and explore how it fit with NGSS teaching. Conversations during this workshop session covered science content, alignment to NGSS, pedagogy, and collaborative reflection. The participating teachers were expected to share the day's ideas and experiences with colleagues in their own buildings. In this way program designers were able to closely reach the workshop participants, but the learning had the potential to reach many more (Bills et al., 2017). The workshop series provided participants with creative, three-dimensional, NGSS-appropriate science lessons that could be immediately implemented in the classroom. Many participants found the live interaction between the master teacher and the students the most instructive and impactful part of the workshop design (Bills et al., 2017). This workshop series, although relatively short-length and intermittent, occurring only four times a year, directly addressed a need identified by its participants and offered material that could be immediately incorporated into teaching practice.

In another example of nonformal PD using experienced teachers, twenty-four "expert" teachers proficient in NGSS three-dimensional learning received additional training in group facilitation and NGSS (Reiser et al., 2017). In a deliberate effort to reach more teachers with NGSS PD, these "experts" were sent to twenty-two locations across the state where they met with other teachers in study groups. Each group used the same PD program: discussing three-dimensional science activities, student learning, and classroom student-teacher interactions (Reiser et al., 2017). Groups met for three to five hours a day nine times over a three-week period. Participants were surveyed about their perceived three-dimensional science instruction proficiency and changes in beliefs and confidence. Researchers found that the participants had a greater understanding of the importance of the students' role in knowledge-building that is central to NGSS after the study group series (Reiser et al., 2017). Teacher confidence in NGSS teaching was also positively affected by the PD opportunity. This PD opportunity utilized local NGSS "experts" as resources for extending knowledge and understanding of some of the more challenging aspects of NGSS instruction to teachers and school districts across an entire state.

Not all nonformal PD programs are successful at influencing teacher practice. A content specific, two-day long program was designed to help science teachers offer inquiry-based instruction about energy (Seraphin, Philippoff, Parisky, Degnan, & Warren, 2013). As an NGSS disciplinary core idea (DCI), energy is a major topic, it is an entire standard with requirements dispersed throughout the K-12 curriculum. Focused on inquiry-based instruction around the topic of energy, this two-day workshop offered instruction, materials, and time to explore the materials. Despite the guidance through possible inquiry-based activities, participants showed negligible changes in confidence with inquiry-based instruction following this PD program (Seraphin et al., 2013). In another study, longer courses, one to two weeks, were found to be ineffective. They "left [participants] with little of lasting value" (McDermott, 2006, p. 760). Short-term PD may be content-specific, involve active learning, and be coherent with the participant's and system's expectations and needs. Without the sustained and recursive attention on a specific topic many teachers did not realize durable changes in beliefs, knowledge, or teaching practice.

Nonformal learning experiences represent the majority of PD utilized by science teachers (Banilower et al., 2013). In isolation, formal and nonformal PD often does not influence teaching practices and cause change (Herrington & Daubenmire, 2016; Yezierski & Herrington, 2011). Jones and Dexter (2014) suggested that these PD experiences may serve another role: formal and nonformal PD experiences introduce information to the inservice teacher; subsequent informal learning provides reflection and action on that information. Teachers may not realize learning or appreciate the value of the formal or nonformal PD experiences until they have devoted time and energy to that idea during informal learning. Informal learning contributes to the learning and transfer process and is often reliant on information gathered from previous formal or nonformal PD experiences.

Informal Learning

Informal learning occurs "outside the curriculum of formal and non-formal educational institutions and programs" (Schugurensky, 2000, p. 1). Informal learning is "learning taking place where no PD trajectory or learning community has been explicitly organized to foster teacher learning" (Hoekstra & Korthagen, 2011, p. 76). Informal learning occurs without systemic support of that learning (Hoekstra, Brekelmans, Beijaard, & Korthagen, 2009). There does not need to be deliberate effort, a curriculum, or a specific learning environment (Desimone, 2009; Richter et al., 2011). Informal learning is often not recognized as learning or part of teacher professional development; much of the informal learning is invisible or taken for granted (Anagnou & Fragoulis, 2014; Eraut, 2004). The preceding comments suggest a general description of this critical form of learning that is often overlooked as part of teacher PD.

Informal learning can and often does occur during or as a result of routine, daily activities. Most teachers regularly spend time reading professional literature, a form of informal learning (Desimone, 2009; Parise & Spillane, 2010). Searching the internet for content material and instructional activities is also a form of informal learning that is rarely recognized as professional learning (Lohman, 2000), especially when the teacher experiments with new material in the classroom (Eraut, 2004) . Observing other teachers, regardless of context, provides learning opportunities outside of any structured environment (Desimone, 2009; Parise & Spillane, 2010). All of these are part of most teachers' routine activities. Each of these presents opportunities for teachers to grow, learn, and modify teaching practice. Perhaps the most important aspect of informal learning is informal collaboration with colleagues. This can take the form of casual mentoring during the day, study groups, or informal teacher networks (Desimone, 2009; Parise & Spillane, 2010). The networking provided during collaboration solidifies or encourages re-consideration of teaching practice beliefs (Lohman, 2000; Lom & Sullenger, 2010). "New understandings develop and new classroom practices emerge in the context of teachers' collaborations with peers and experts" (Anderson, 2002, p. 9). Many aspects of informal learning — professional reading, observing peers, networking, collaboration — contribute to every teacher's professional learning and growth.

Often the only learning experiences that were considered PD by teachers and administrators were the classes, workshops and professional learning community meetings - formal and nonformal learning opportunities. While those are important and often influence or inform teacher learning (Jones & Dexter, 2014), the informal learning may be more important

(Lom & Sullenger, 2010; Stevenson, 2004) to teaching practice. The informal learning from the hallway conversations that provides "immediate support, new idea generation and brainstorming opportunities" (Jones & Dexter, 2014, p. 369) is vital to teacher learning. All learning experiences, formal, nonformal, and informal, contribute to teacher learning. All serve a purpose in the long-term PD of every teacher.

Next Generation Science Standards Professional Development

The National Research Council (2015) and scholars (Bybee, 2014; Singer, Ross, & Jackson-Lee, 2016) acknowledged that current and incoming science teachers would need extensive PD as states and districts adopted and implemented NGSS. NGSS PD facilitators need to be mindful of several key components of any quality PD experience: content specific, connected to practice, coherence, encouraging of reflection, and sustainable (Garet et al., 2001; Wilson, 2013).   NGSS PD would be necessary not just for the teaching staff, but for all involved in the science curriculum process: state education department personnel, district and building administrators, and K-12 science teachers (Harris et al, 2017; National Research Council, 2015). Each of these groups has key roles in determination of the science content requirements, student learning goals, and assessment of student learning; all must understand the complexities and expectations of NGSS instruction.

Teaching with NGSS presents additional, unique challenges. NGSS is a novel way of approaching the teaching of science. It is not enough for classroom teachers to learn about NGSS and attempt to modify teaching practice and assessments for the new standards; changes and implementation have to begin at the leadership levels: state, district, and building level (National Research Council, 2015). NGSS will affect every aspect of science instruction: teaching practice, assessment, curriculum materials, and other resources. All involved from the state level through the classroom teacher need to understand why and how these changes would affect science education.

Science teachers need support in several key areas: inquiry, scientific argumentation, and science and engineering practices (Capps et al., 2012; Reiser, 2013). Science and engineering practices (SEPs) are integrated throughout the standards and across all grade levels, including the elementary grades. Most teachers lack knowledge of engineering applications and experience teaching engineering practices (Banilower et al., 2013; Singer et al., 2016). NGSS represents a shift from traditional teaching practices; it will require a comprehensive, multi-year plan to update and encourage current science teachers to modify teaching practices (National Research Council, 2015). It is not realistic to expect practicing science teachers to understand or embrace the changes required of them within a relatively short timeframe. The PD will need to be deliberate and sustained for there to be real change for most science teachers.

Summary

Teacher professional development (PD) offers practicing teachers opportunities to explore topics that could impact their professional practice. The learners, the practicing teachers, determine the value of the PD content (Bowman, Jr. & Govett, 2015; Herrington & Daubenmire, 2016; Smith & Lindsay, 2016). Quality PD experiences are content-specific, coherent, sustained, and encourage collaboration reflection (Beerer & Bodzin, 2004; Capps et al., 2012; Garet et al., 2001; Herrington & Daubenmire, 2016; Kazempour, 2009; Lustick, 2011). Teachers access professional learning through formal, nonformal, and informal experiences. Regardles of the PD format or delivery system, all involved with science education — classroom teachers, administrators, and district and state education officials — will need NGSS-specific education featuring information on teaching practices, assessments, curriculum materials, inquiry, scientific argumentation, and science and engineering practices.

Adult Learning

The authors of NSES and NGSS realized the science teaching community would need professional development focused on the changing expectations of the new standards (National Research Council, 1996, 2013a, 2013b, 2015). Teacher learning should follow the expectations of the K-12 science education: learning through inquiry; integrating all aspects of science learning – content, pedagogy, and real-life situations; persisting entire teaching career; and offering a coherent and integrated program of learning opportunities (National Research Council, 1996). Science teacher education, including PD, is a component of adult education as it includes "activities intentionally designed for the purpose of bringing about learning among those whose age, social roles, or self-perception define them as adults" (Merriam & Brockett, 2007, p. 8).

Science teacher PD opportunities feature several key ideas: learning in a social environment with peers (Bills et al., 2017; Blasie & Palladino, 2005); learning from and with others with greater experience (Bills et al., 2017; Reiser et al., 2017; Vick, 2017); learning with a community of practice (Desimone, 2009; Jones & Dexter, 2014; McGee & Nutakki, 2017; Parise & Spillane, 2010); and learning through reflection (Jones & Dexter, 2014; Lohman, 2000; Lom & Sullenger, 2010). Those concepts correspond to specific adult learning frameworks or theories: social learning theory, experiential learning, community of practice, and reflective learning.

Social Learning Theory

Social learning theory acknowledges that "people learn from observing others" (Merriam et al., 2007, p. 287). Most learning occurs in social settings (Bandura, 1977). Learning can take place with or without imitation of a behavior, the observation of social interactions is the most important aspect for the learner. Learning requires a social setting and the observation of behaviors, but it is the cognitive process by the learner that is necessary for change or growth by the learner (Bandura, 1977, 1986).

Bandura (1977) identified four critical components to the social learning process: attention, retention, rehearsal, and motivation. As a first step, the learner must be aware of a behavior and dedicate some portion of his or her attention to that behavior. That behavior must be notable and significant to the learner, so there is a memory for the learner to draw upon for future applications. Assuming the learner finds value in the behavior usage, the next step in the social learning process is reproduction, or replication, of the behavior. Accompanying the reproduction of the behavior is the element of motivation. Learners need to find value or rationale to model the original behavior. Lacking any one of these factors — attention, retention, rehearsal, or motivation — the learner will not experience social learning.

Social learning theory extended beyond the original framework of behaviorist learning to incorporate cognitive elements (Merriam et al., 2007). Social learning is more than repetition of a behavior, it involves deliberate effort and decision to avoid a behavior or incorporate that desired behavior into the learner's subsequent actions. Bandura's social learning theory combined modeling of behavior with the learner applying thought and attention to the implications of adopting a similar behavior.

Experiential Learning

Social learning theory explains learning that occurs based on learner observations and the implementation of the observed behaviors; experiential learning addresses learning that occurs as a result of the learner's participation in activities (Merriam et al., 2007). Experiential learning is an active learning opportunity that is governed by the learner and corresponds to a real-life situation or environment (Illeris, 2007). Experiential learning can be deliberately organized or incidental to life events.

Kolb (1984) proposed the experiential model of learning which consists of four key components: concrete experiences, observation and reflection, analysis and generalization, and application. Kolb (1984) suggested that the four parts work in a sequence and when the learner gets to the application phase the cycle re-starts; as the learner applies knowledge and expectations and produces new experiences those new experiences warrant additional observation and reflection.

Each of the four parts of Kolb's model is essential to learning. There must be a physical or concrete experience that attracted the attention of the learner. Learners have to be aware of the experience and have to make connections between the new experiences and other similar occurrences. This reflection is essential to the learning process (Kolb, 1984; Merriam et al., 2007) and offers learners the opportunity to "attach meanings to or make sense of their experience" (Merriam & Brockett, 2007, p. 153). Analysis and generalization allows the learner to make predictions about similar situations or applications (Merriam et al., 2007). If any of these features is absent there will be no new knowledge or application by the learner.

Adult learners encounter experiential learning opportunities in many venues: apprenticeship, internship, practicum, study abroad, research, service learning, and leadership opportunities (Merriam & Brockett, 2007; Merriam et al., 2007). Each of these settings immerse the learner in an activity or experience that could be an avenue for learning. Teacher education and PD programs feature many of these experiential learning activities.

Community of Practice

Experiential learning can be viewed through many lenses. Kolb (1984) relied upon a constructivist point of view to explain the learning based on experience described above. Lave (1991) and Wenger (1998) chose to take a situated framework through which to view experience and learning in their evaluation of communities of practice and their influence on learning. Situated learning recognizes that any learning is dependent on and influenced by the context of that learning (Merriam et al., 2007). Communities of practice are centered around a common context or situation. A community of practice is composed of a group of interacting individuals that are engaged in practice of a common interest (Lave & Wenger, 1991). All three aspects — community, interaction, and shared practice — are necessary for the group to be considered a community of practice and contribute to the learning of its group members and development of shared meaning-making.

Communities of practice are frequent learning opportunities in education. Commonly referred to as professional learning communities, these groups assemble school administrators, teachers, and others with common interests into an environment that allows discussion and collaboration to support learning by the individuals and the group (Hamos et al., 2009). Despite the alternate label, the professional learning community serves the same function as the community of practice identified by Lave and Wenger (1991): providing a social experience that can foster collaboration and learning. Beyond providing support to its members, the community of practice or professional learning community "can engender a sense of the excitement of learning that is then transferred to the classroom, conferring a sense of ownership of new ideas as they apply to theory and practice" (Bransford et al., 2000, p. 25). Communities of practice combine the experiences of their members with the social interaction and collaboration that encourages learning by all involved.

Reflective Learning

Reflection has been identified as a key component of quality PD experiences (Beerer & Bodzin, 2004; Capps et al., 2012; Kazempour, 2009). Dewey (1933) was given credit for initiating conversations about the value of individual reflection as a method of learning. Reflection "is a deliberate pause to assume an open perspective, to allow for higher-level thinking processes" (York-Barr, Sommers, Ghere, & Montie, 2001, p. 6). Dewey and others (Kolb, 1984; Schön, 1983, 1987) suggested that individuals used the examination of beliefs and experiences to change and improve teaching practice. Schön (1983) proposed that two aspects of reflection, reflection-in-action and reflection-on-action, contribute to learning, especially in the workplace.

Reflective learning requires three essential efforts by the learner: deliberate thought on the situation, questioning or criticizing the circumstances, and some effort to resolve or address the issue (Schön, 1987). Reflective learning assumes the learner has some experience with similar contexts or applications and can draw on that experience to influence subsequent actions and decisions. Schön's (1983) reflection-in-action and reflection-on-action describes the timeliness of the learner's reflection. The -in-action is the immediate response to circumstances. Any thought is very brief; it is the spontaneous or automatic response to a situation based on previous experiences, feelings, and understandings. Reflection-on-action is the retroactive review upon an event that offers an opportunity to consider what happened, to analyze the choices made, and to consider the outcomes of those decisions (Schön, 1983). Each of these two aspects of reflection, in-action and on-action, require the learner to engage existing knowledge, analyze the context, and implement a selected strategy for managing the situation. The process contributes to the learner's existing knowledge base regardless of the timeliness of the application of the reflective thinking.

Schön's views on reflective learning were not without critics. Eraut (1994) questioned the time needed for reflection as it applied to reflection-in-action: "When time is extremely short, decisions have to be rapid and the scope for reflection is extremely limited" (p. 145). Eraut seemed to suggest that, given the immediacy of the response, there would not be legitimate reflection that allowed the learner to review possible reactions, but simply a response to the situation. Schön was ambiguous on the requirement of praxis based on the reflection. Richardson (1990) suggested that Schön's (1983) language and presentation highlighted the thought process involved in reflection but did not require a resulting action. Usher, Bryant, and Johnston (1997) argued that Schön should have demonstrated his own reflective learning during the presentation of his ideas. Despite the criticisms surrounding Schön's version of reflective learning, scholars and adult educators continue to refer to this framework of learning.

Summary

Social learning, experiential learning, community of practice, and reflective learning are only a few of the theories or frameworks that are available to researchers to describe adult learning. Each of these recognizes many of the characteristics of the adult learner: self-directed, problem-centered, and internally motivated and reinforces a framework of learning represented in the Next Generation Science Standards: includes inquiry learning, is persistent, and incorporates real-life situations. Social learning theory requires the learner to observe social interactions and use those interactions as a learning opportunity (Bandura, 1977). Experiential learning is dependent upon the learner having concrete experiences that could offer opportunity for observation and reflection, analysis and generalization, and subsequent application (Kolb, 1984). Community of practice incorporates experiential learning in a specific situation; community of practice learning requires a common community with a shared practice and interaction between the participants (Lave & Wenger, 1991). Reflective learning requires the learner to make the effort to deliberately think about the situation, question or criticize the circumstances, and make an effort to resolve or address the issue (Schön, 1987).

Transfer of Learning

Teachers participate in PD in a variety of formal, nonformal, and informal learning circumstances. Those experiences contribute to teacher knowledge, but real value is evident when that learning and knowledge is transferred to teaching practice. The following section will offer a brief history of transfer of learning, an explanation of Dufresne et al.'s (2005) description of transfer of learning, examples of teacher learning transfer of PD to the classroom, a list of factors that promote learning transfer, and a collection of barriers to transfer of learning. Each of these topics are important to understanding transfer of learning.

Brief History of Transfer of Learning

Transfer of learning, as utilized in this study, can be defined as "a complex dynamic process leading to the highly selective activation and application of knowledge in response to context" (Dufresne et al., 2005, pp. 155-156). The understanding and description of transfer of learning has gone through transitions as researchers have attempted to understand what it means to utilize material that has been learned in alternate settings.

The concept of transfer of learning was initially presented as "transfer of practice" (Woodworth & Thorndike, 1901, para. 31). Woodworth and Thorndike (1901) conducted the first documented study of how learning might transfer from one context to another. After this early introduction of the idea of transfer, the topic, under a variety of related labels, has been studied by cognitive psychologists, business trainers, and educational researchers (Haskell, 2001). The work of this last group, the educational researchers, provided the material for the remainder of this history of transfer of learning. Transfer of learning has been categorized in many ways. A few of those frequently applied in educational research will be reviewed.

Haskell (2001) suggested that transfer of learning "is our use of past learning when learning something new and the application of that learning to both similar and new situations" (p. xiii). Haskell (2001), in an attempt to organize or categorize transfer of learning, proposed six levels of transfer: nonspecific transfer, application transfer, context transfer, near transfer, far transfer, and displacement or creative transfer (pp. 29 - 30), In this manner, Haskell provided labels for simple transfer of a new skill in the intended manner (application) or more complex situations of extrapolation of learned skill into a novel situation (displacement or creative transfer). Haskell (2001) further classified transfer of learning based on type of knowledge transferred and the kinds of transfer. Haskell provided a complex taxonomy of transfer of learning not seen in other educational research descriptions.

In another perspective, Broudy (1977) categorized transfer of learning according to the manner in which learning was used: replicative — duplicating the content or skill directly from the learning experience to practice, applicative — utilizing the content or skill with adaptations or in a different context, associatively — connecting previous experiences to new activities, or interpretively — applying logic and patterns to guide expectations about the new experiences. Each of these transfer modes could be part of every teacher PD experience. Broudy's view of transfer of learning over-simplified the transfer process and overlooked the importance and learning and application context (Bransford & Schwartz, 1999).

Bransford and Schwartz (1999) expanded on Broudy and other researchers' work on transfer of learning. Focusing on assessment of learning transfer, Bransford and Schwartz (1999) explained that replicative and applicative transfer of learning was typically assessed by "sequestered problem solving" (p. 68). In this type of assessment, learners were provided with a novel problem that could be solved by the skills recently learned. Learners were expected to use appropriate information (replicative) and skills but apply them to the novel situation. Despite repeated attempts by multiple groups, researchers failed to find evidence of transfer of learning, leading Detterman and Sternberg (1993) and others (Bransford & Schwartz, 1999; Broudy, 1977; Schwartz, Bransford, & Sears, 2005) to conclude that transfer of learning was a rare occurrence. Bransford and Schwartz (1999) suggested that the reason researchers failed to find transfer of learning was the assessment tool used by most: sequestered problem solving.

In a critique of sequestered problem solving as a method of assessing transfer of learning, Bransford and Schwartz (1999) highlighted a fundamental flaw in the method and its requirements. "There were no opportunities for them to demonstrate their abilities to learn to solve new problems by seeking help … or by trying things out, receiving feedback, and getting opportunities to revise" (Bransford & Schwartz, 1999, p. 68). In response to this void, Bransford and Schwartz (1999) proposed to assess transfer of learning through the lens of "preparation for future learning" (p. 68). This recognition of future learning allowed researchers to assess Broudy's interpretive learning component and accommodated situational context during an assessment of transfer of learning. Preparation for learning implied that transfer was a dynamic, everchanging process, not a discrete occurrence.

Other perspectives are available on transfer of learning. Bransford et al., (2000) suggested four key characteristics of learning as applied to transfer: the need for initial learning, the abstract and context-driven nature of knowledge, the active and dynamic characteristics of learning, and the idea that all learning constitutes transfer. In a similar direction of thought, Schwartz, Bransford and Sears (2005) furthered the conversation about transfer of learning, suggesting that “we need to rethink the impact of different educational experiences for preparing people to learn” (p. 20). Transfer of learning could be evaluated based on learners demonstrating a transfer of new knowledge or practices from a learning experience. Schwartz et al. (2005) advocated attention to the importance not just on the learning coming out of an experience, but also awareness of learning and knowledge imported into an educational experience. Transfer of learning needed to be recognized as a multi-directional experience. Only evaluating transfer of learning from the perspective of knowledge coming out of an experience, as had been done in previous research studies, overlooked a significant component of learning.

In addition to a recognition of alternate representations of transfer of learning, Schwartz et al. (2005) suggested a replacement to Broudy’s (1977) transfer terminology of replicative, applicative, associative, and interpretive learning. They recommended viewing transfer of learning in terms of efficiency and innovation. Efficiency of learning and transfer acknowledged the learner’s ability to access and utilize knowledge and skills required in a given task (Schwartz et al., 2005). Efficiency, in this context, incorporated the transfer dimensions of replication and application. Innovation combined Broudy’s (1977) interpretation with thinking and creativity and required the learner to extend existing knowledge and skills beyond typical usage. Regardless of the language used to describe transfer, there was usage, direct or indirect, of knowledge or skills acquired or improved during learning that was utilized directly or as a foundation for future applications.

Schwartz et al. (2005) contributed three key ideas that were reinforced by the work of Dufresne et al. (2005): 1) the value of existing knowledge imported into the learning experience, 2) efficiency of transfer of learning, and 3) innovation through transfer of learning. Transfer of learning was complex, involving existing knowledge and skills; transfer of learning was context dependent and could be manifested in many ways. For example, transfer of learning could be the reproduction or redeployment of learned skill, a modification of learning to fit the current circumstances, or the innovation of new strategies from existing knowledge and new gained knowledge. Dufresne et al. (2005) stressed the importance of context and the "activation and application of knowledge" (p. 156). Schwartz et al. (2005) incorporated a similar idea with the discussion of efficiency and innovation.

Transfer of learning into experiences and out of experiences was complicated. Learners had to find a balance between their existing knowledge, practices, and beliefs and new learning if there was to be a transfer of new skills and knowledge to subsequent practice (Bransford et al., 2000; Schwartz et al., 2005). There was not a defined pattern to learning and the transfer of that learning. "Transfer is inherently nonlinear and chaotic" (Dufresne et al., 2005, p. 161). Even as each teacher determined his or her understanding of any PD or other learning experience (Bowman, Jr. & Govett, 2015; Herrington & Daubenmire, 2016), the content and manner of that understanding was unique for each individual.

Dufresne et al.'s Transfer of Learning

Dufresne et al. (2005) incorporated many of the ideas presented in previous descriptions of transfer of learning. Highlighting existing knowledge, application, and context, Dufresne et al. (2005) defined transfer of learning as "a complex dynamic process leading to the highly selective activation and application of knowledge in response to context" (pp. 155-156). This description removed the concern about appropriateness or correctness of application implied by other definitions of transfer of learning (Bransford & Schwartz, 1999; Broudy, 1977) and acknowledged the learner's usage of any existing knowledge.

Dufresne et al. (2005) viewed transfer of learning as a common occurrence, noting "a knowledge user continually faces new contexts, and in response, a subset of his or her existing knowledge is activated and applied" (p. 158). With this perspective, transfer of learning happens with all individuals, in every context. That assumption allowed Dufresne et al. to explore other aspects of transfer of learning: the process, the dynamics, and the validity and viability of the transfer.

The process of transfer of learning involves the use of knowledge and application of that knowledge (Dufresne et al., 2005). Observations of a situation provide the learner with a set of information or readouts. These observations are combined, often without awareness, with the learner's expectations or beliefs. This combination contributes to an awareness or understanding of the context of the situation, enabling the learner to engage and apply some piece of knowledge to the current situation (Dufresne et al., 2005). This description of the process would not be complete without the influence of context on the dynamics of the transfer.

Dufresne et al. believed that transfer of learning is commonplace and occurs routinely. Coupled with this acknowledgment is the understanding that transfer is not a simple or straightforward process. Transfer of learning is "inherently nonlinear and chaotic" (Dufresne et al., 2005, p. 161). Transfer of learning is dynamic, the learner constantly adjusts readouts and observatons in response to actions and expectations. Dufresne et al. (2005) suggested that transfer of learning is an attempt by the learner to establish an equilibrium between observation and expectation. The learner will transfer knowledge in the form of information or actions to the situation to adjust the observations so they more closely match the learner's expectations.

With Dufresne et al.'s view of transfer of learning as an attempt to reach an equilibrium by the learner, there must also be an awareness of the validity or viability of the transfer process. The learner's actions or information may not have contributed to resolution of the situation, as perceived by the learner. In this case transfer occurs but is unsuccessful or incomplete. Dufresne et al. (2005) suggested that this is not unusual. As viewed by the learner, transfer of learning is often inefficient, often incomplete, and greatly influenced by language. Again, this did not suggest that transfer of learning did not occur, only that transfer was not fully successful.

Durfresne et al. (2005) described a learner-driven dynamic process that employs selection and utilization of existing knowledge in a specific setting. Three aspects of learning transfer: 1) the process of the transfer, 2) the dynamics of the transfer, and 3) the validity or viability of the transfer are important to the evaluation of learning transfer. Dufresne et al.'s explanation of transfer of learning requires acknowledgement of the learner's perspective and assumptions. This explanation of transfer of learning respects the critical nature of the context or setting and incorporates the constantly shifting nature of context and perception. All of these factors are important in any learning context, but particularly applicable to teacher education and teaching practice.

Transfer of Learning Research with K-12 Science Teachers

As the definition and understanding of transfer of learning expanded, the studies identifying transfer increased, including reports of successful transfer of learning by science teachers. Van Duzor (2011) conducted a study with elementary teachers centered around a science PD program. Immediately following the learning experience, the teacher-participants implemented the teaching practices and experiments. Even more encouraging, some participants expanded upon the material presented in the PD and modified or expanded existing classroom activities as a response to the PD experience (Van Duzor, 2011). These transfers, duplication of PD material and expansion beyond the instructional material, represented “activation and application of knowledge in response to context” (Dufresne et al., 2005, pp. 155-156). Those teachers who were able and willing to expand their teaching practice and content beyond the instructional material demonstrated the ability to apply existing and new knowledge in the context of the classroom environment.

In another study of elementary school teachers and science content, Harlow (2014) had similar findings. Following fifteen hours of PD conducted over a six-week period, some of the study’s participants transferred content and used that content within current teaching practices. Others utilized new content and teaching practices in the classroom after the PD experience. Lom and Sullenger (2010) explored the informal learning and experiences of elementary and middle school teachers involved with a Science in Action collaboration of teachers, representatives of local science organizations, and science educators. Teachers and researchers identified transfer of learning: changes in teachers’ interactions with students, utilizing new technology and other resources, and modifications to lessons — planning, content, and/or activities. Similar results were found in a multi-phase, year-long PD experience focused on engineering principles in the high school classroom (Hardré et al., 2018). Researchers found that participants utilized content, expertise, and skills presented during the PD experience in the classroom. An additional and ambitious result was that the PD “experience supported participating teachers in their efforts to translate their own learning into authentic, inquiry-based curricula for their own classes” (Hardré et al., 2018, p. 79). These participants were able to assimilate teaching, planning, and implementation strategies modeled during the year-long program into their own teaching practice. Both studies had similar goals and research questions; the biggest difference was the PD duration: fifteen hours over six weeks compared with a year-long program.

In some instances, study participants' learning and transfer of learning went beyond content knowledge and pedagogy. One elementary school teacher had difficulty understanding a science presentation during a PD session. She realized that if she did not understand the concept her students would have similar challenges. For this teacher, attempting to transfer PD instruction to the classroom informed the teacher of her own learning needs (Van Duzor, 2012). Other study participants noted a shift in science pedagogy that went beyond the content of the current PD. As they learned about effective science pedagogy, some teachers came to understand the crucial role their teaching practice choices had in the quality of student learning (Smith & Lindsay, 2016). That awareness has the potential to influence all subsequent science teaching choices. In a similar moment of learning that extended beyond any content, one study participant noted "it was not what they *had* done at … [the PD] but what they *had learned* and most meaningfully internalized that they took back to their students" (Hardré et al., 2017, p. 259). For this participant, the transfer of learning was complex and influenced attitudes and beliefs as much or more than science content and teaching practice.

Factors supporting transfer of learning identified by researchers

Several factors have been identified as playing a role in supporting teacher transfer of learning and knowledge from PD settings to the classroom. Teachers need an adequate amount of knowledge to allow for transfer of learning (Bransford et al., 2000; Dufresne et al., 2005); PD providers need to consider the context of their learners, especially if the teachers perceived a need for the PD topic (Barnes, Hodge, Parker, & Koroly, 2006; Van Duzor, 2011); and teachers need to have opportunities to collaborate with colleagues (Baker-Doyle & Yoon, 2011; Bransford et al., 2000; Hardré et al., 2017; Jones & Dexter, 2014). One or more of these features was present when researchers were able to identify transfer of learning from PD to classroom practice.

Professional development (PD) is a continuation of education, not a beginning. Learning, and subsequent transfer of that learning requires an existing layer of knowledge or understanding of the topic being addressed (Dufresne et al., 2005). If there is an inadequate amount of "initial learning" (Bransford et al., 2000, p. 53) during the PD experience there will be no new content or pedagogy to transfer to classroom practice. Each PD experience has to provide enough information to influence each learner's desire to implement changes in teaching content or practice.

Context is also critical for transfer of learning, especially in the organization, design, and execution of PD programs. Teachers are more motivated to learn and more likely to transfer PD content and pedagogy to the classroom if they feel they can be successful with the new skills (Barnes et al., 2006). Equally important is the teachers' perceptions of students' needs. Transfer of learning is more likely if teachers found the content directly addressed students' needs (Barnes et al., 2006; Van Duzor, 2011). Teachers who felt a greater need for the material presented in the PD or who had more freedom to make instructional changes are more likely to transfer learning after PD (Van Duzor, 2011). Each teacher has a unique context as he/she enters a PD experience; any learning or transfer of learning will be determined by the individual teacher based on his or her perceptions of the applicability of that PD to his or her teaching needs.

The most important factor researchers noted in transfer of learning for teachers was the availability of peer collaboration. This peer collaboration can range from a very involved mentor relationship to casual social support. Baker-Doyle and Yoon (2011) documented the importance of relevant knowledge from PD coupled with social support as key factors in transfer of learning, especially for enduring teaching practice changes. PD participants engaged in a year-long program noted the importance of collaboration with the PD facilitators and with their peers, drawing attention to the significance of "the opportunity to share ideas with peers teaching similar classes and students as an important factor in their development and more specifically their preparation to transfer the content back to their schools" (Hardré et al., 2017, p. 255). Other researchers (Jones & Dexter, 2014; Bransford et al., 2000) reported on the contributions of informal collaborations and other informal learning opportunities to the transfer of learning from structured PD. Teachers valued the opportunity to discuss content, skills, and teaching practices with colleagues, especially those who taught similar material. This aspect of informal learning is particularly important for transfer of learning from PD to the classroom.

Failed Transfer of Learning

Even with the greatest support, there is no guarantee that teachers' learning will be transferred to teaching practice. "Transfer into practice *at all* is often tricky, even with the best professional development" (Saphier, 2017, p. 66). Many factors, mostly personal or contextual, could interfere with successful transfer. Even if transfer of learning occurred some teachers reverted to their original teaching practices (Lustick, 2011). Transfer of learning is never certain. Deliberate efforts to avoid some of the identifiable challenges to transfer will benefit the teacher-learners.

Many of the issues researchers recognize as instrumental in failed transfer of learning are dependent upon the learner. McAlpine and Weston (2002) identified several personal characteristics that could influence transfer of learning for college professors: lack of experience or content knowledge, inability to read classroom cues, and fear of risk-taking. These same characteristics could influence teachers of any grade level. Some teachers learned content or teaching practices during PD but made deliberate decisions to not use those skills in the classroom (Lustick, 2011). These findings were consistent with Enderle et al.'s (2014) and Hewson's (2007) recognition of the control learners had over the incorporation of learning in subsequent teaching practice. The learner determines what information has value and how that information is transferred to future teaching practice.

Context plays a role in teachers failing to transfer learning into practice. If the content or pedagogy introduced during the PD is not a priority for the learner, there was no transfer to teaching practice (Saphier, 2017). It is not enough to spend time learning and talking about the desired teaching skills or content, the teachers have to find the time and value to deliberately focus on using that PD in the classroom. In other cases, teachers only value the parts of the PD that are similar to their existing teaching practice. Rather than recognize the new or unique characteristics of content or teaching skills, teachers note the parts of the PD that are familiar and "learn" those features, effectively failing to learn or transfer the new content and skills (Schwartz, Chase, & Bransford, 2012). That description is consistent with the experiences of some teachers following professional development programs for California's 1985 adoption of a new mathematics curriculum, the *Mathematics Framework*. Teachers made modifications to practice, but "they did so in terms of their pre-existing practice, knowledge and beliefs. They framed the policy in terms of what they already knew, believed, and did in the classrooms"

(Cohen & Ball, 1990, p. 331). Darling-Hammond (1990) noted “that teachers’ decisions and actions are grounded in what they have experienced and what they came to know and believe long before this curriculum was introduced” (p. 345). The teachers made small changes to teaching practices following the adoption of curriculum, but those changes emphasized the similarities of pre-existing curriculum and teaching practices and failed to acknowledge important differences with current instructional methods.

The complexity of teaching with NGSS can contribute to the inability of teachers to transfer learning. NGSS is a unique combination of specialized terminology, detailed science content, and learning through science and engineering practices (Furtak & Penuel, 2019; Melville, Dowdle, & Campbell, 2015). Nadelson, Seifert, and Hendricks (2015) surveyed K-12 teachers after they participated in a week-long, 45 hours, program of courses on STEM topics and NGSS SEP. Since the program specifically emphasized the science and engineering practices, researchers expected, and found, that the participants reported an increased awareness and knowledge of the SEP. Unfortunately, despite the increased familiarity with SEP, many study participants were not confident they could transfer SEP knowledge to classroom practice (Nadelson et al., 2015).

Friedrichsen and Barnett (2018) followed a biology professional learning community (PLC) during the first year of NGSS implementation. The six teachers independently read and studied the NGSS documents, then met as a group to plan the biology course for the year. Despite the time and efforts spent individually and as a group, the teachers missed key ideas of teaching with NGSS. “They interpreted the NGSS PEs as adding skills and reducing science content details” (Friedrichsen & Barnett, 2018, p. 1019). The group assessed science skills, the SEP, separately from science content; NGSS specifically advocates for a combination of the CC, SEP, and science content during instruction, learning, and assessment (National Research Council, 2013a) and excluded engineering from the biology course. This PLC had the NGSS information and ideas available to them, they transferred some information to implementation – content reduction – and failed to incorporate other key NGSS ideas.

Summary

Transfer of learning has been described in many different way based on the manner learning was applied to new circumstances (Broudy, 1977; Haskell, 2001). Other concerns involved the identification and assessment of transfer of learning (Bransford & Schwartz, 1999). Dufresne et al. (2005) combined many of these ideas and described transfer of learning in terms of the process, the dynamics of the process, and the validity and viability of the transfer. Research has suggested that transfer of learning is supported when the participant identified new knowledge in the PD experience, had opportunities for collaboration, and was motivated to transfer learning to practice. Transfer of learning was prevented or minimized based on learner characteristics and other factors such as PD context and application venue.

Chapter Summary

Science standards in the United States have undergone great changes over the last three decades, beginning with the influence of *Science for All Americans* and culminating in the considerable changes manifested in the Next Generation Science Standards (NGSS). Current teachers, as adult learners, will explore and learn about NGSS through formal professional development, nonformal professional development, and informal learning experiences. Teacher PD and learning is only useful to the implementation of NGSS if teachers transfer that learning to classroom practice.

A few studies on science teacher transfer of learning have been published; most utilized elementary and middle school teacher participants (Harlow, 2014; Lom & Sullenger, 2010; Van Duzor, 2011). Nadelson et al. (2015) surveyed K-12 teachers following a week-long PD program and Friedrichsen and Barnett (2018) followed a biology professional learning community as the group implemented NGSS. There is no research that specifically explores how veteran high school science teachers learn about NGSS and how that learning transfers to classroom practice. That gap — the experiences of veteran high school science teachers as they learn about NGSS during formal professional development, nonformal professional development, and informal learning and the transfer of that learning to the teaching practice — suggested this study's purpose. This qualitative case study is designed to explore how veteran high school science teachers describe their knowledge of the NGSS, how professional development and other learning experiences impacts their knowledge and understanding of NGSS content and teaching practices, and how those teachers are transferring PD and the NGSS goals of inquiry, science and engineering practices, and scientific argumentation to the classroom. Transfer of learning is a key component to effective NGSS implementation; transfer of learning, combined with learning delivery mode and learning frameworks, will be the conceptual framework for this research study.

Chapter 3: Methodology

Introduction

This was a qualitative multi-case study designed to explore how veteran high school science teachers described their knowledge of the Next Generation Science Standards (NGSS); how formal professional development (PD), nonformal PD, and informal learning impacted participants NGSS knowledge; and how those teachers were transferring NGSS knowledge and NGSS goals of inquiry, science and engineering practices, and scientific argumentation to the classroom. The conceptual frameworks of NGSS, learning delivery mode and transfer of learning were utilized during the data collection and data analysis. Data were gathered from semi-structured interviews, classroom observations, and document analysis.

This chapter presents a purpose statement and the associated research questions. The case study methodology is described including a rationale for the methodology, a description of the research population, and a summary of the research design. The theoretical framework of symbolic interactionism and the conceptual frameworks of NGSS, learning delivery mode, and transfer of learning is described, as each relates to this study. Information about data collection methods and a pilot study is introduced. Descriptions of the protection of human subjects, reciprocity, ethics, data management, and data analysis are included to support the ~~validity~~ trustworthiness of the research. The chapter closes with information on researcher subjectivity and a chapter summary.

Purpose Statement

The majority of current science teachers are not prepared to teach science incorporating the three-dimensional approach prescribed by the NGSS authors and the NGSS. Any gaps in teacher content knowledge and pedagogy will need to be filled by PD; however, there are many questions about what will be transferred from those PD experiences to classroom practice. The purpose of this study was to explore the formal, nonformal and informal ways that veteran high school science teachers describe their learning about NGSS and how those teachers are transferring NGSS knowledge and the NGSS goals of inquiry, science and engineering practices, and scientific argumentation to the classroom.

Research Questions

The specific research questions for this study are:

1. How do veteran high school science teachers describe NGSS?
2. How do veteran high school science teachers describe their NGSS-focused experiences according to the classifications of formal, nonformal, and informal learning?
3. How do veteran high school science teachers transfer knowledge and modify teaching practices and science content as they incorporate NGSS specified inquiry, science and engineering practices, and scientific argumentation?

Research Design Rationale

This was a qualitative multi-case study with three veteran high school teacher participants. Each teacher has a unique experience with NGSS based on pre-existing knowledge, teaching experience, personal preferences, PD, and other factors (Bowman, Jr. & Govett, 2015; Herrington & Daubenmire, 2016). That may translate to a unique understanding of NGSS and its application and implementation in the classroom. Understanding the influence of teacher learning, PD, and NGSS teaching on subsequent teaching practice will be beneficial to PD developers and science teachers and adult educators. This study sought to add to the body of information about the experiences of veteran science teachers as they learn about and implement NGSS.

Surveys are common instruments in education research. Survey research methods are limited in depth and detail and rely upon self-reporting sometimes leading to questionable results (Capps, Shemwell, & Young, 2016). This study's research questions were not likely to be answered completely even with a well-written survey. Many issues can affect teacher learning and teaching practices - previous teaching experience, preferred learning format, exposure to NGSS content and teaching practices – among many others (National Research Council, 2012; Reiser, 2013; Wilson, 2013). The abundance of influential factors contributes to the complex situation surrounding science teacher knowledge, learning, and transfer to teaching practice; a survey is unlikely to capture that phenomena. The research questions for this study explore the participants' experiences and understandings. Those type of questions will benefit from a deeper exploration available during a case study (Stake, 1995; Yin, 2009). A case study methodology permitted an in-depth exploration of the participants' experiences while respecting the context of each participants' reality (Creswell, 2013; Yin, 2009).

Theoretical Framework

Interpretivism, specifically symbolic interactionism, was the theoretical framework for this study. Interpretivism covers a broad section of qualitative research, including any study "that assume[s] the meaning of human action is inherent in that action" (Schwandt, 2015, p. 169). These meanings are unique and dependent on the social and historical interpretations of the study participants (Blumer, 2004; Crotty, 2015) . Human experiences can only be described if the researcher includes those social and historical elements.

Max Weber is credited with suggesting the importance of understanding, *Verstehen*, to human sciences (Crotty, 2015; Weber, 2009). This began a conversation about social science research and the importance of recognition of the influence of the individual. The area of interpretivism was advanced by Dilthey's (1979) suggestion of the need for social science-specific research methods. The focus of interpretivism was further refined by ideas presented by Windelband (Windelband & Oakes, 1980) and Rickert (1986) with the realization that natural science seeks to find generalizations and consistencies, to find a pattern; human science should not anticipate reproducible patterns (Crotty, 2015). Interpretivism does not attempt to explain common experiences but finds value from examining individual experiences (Blumer, 1986).

Interpretivism can be further divided into several smaller frameworks that vary based on "their attitudes towards culture as our inherited meaning system" (Crotty, 2015). Among those focused theories are the ideas of hermeneutics, phenomenology, and symbolic interactionism. Symbolic interactionism is dependent on three ideas (Blumer, 1986, 2004)

- each individual acts towards objects and others based on his or her own understanding of that object or person
- each individual determines that understanding or meaning from social interaction
- meanings are modified based on subsequent social interactions.

Symbolic interactionism allows the participant and researcher to establish the meanings and value of observations and comments. These meanings are applicable only to the specific situation and participants involved in the study. Of equal or more importance to the actual symbols is the influence of social interactions on the perceptions of study participants (Crotty, 2015). Symbolic interactionism and its emphasis on the meanings imparted and modified by the participant provided the theoretical framework for this study.

Conceptual Framework

Symbolic interactionism was used as the theoretical framework for this case study. The conceptual framework incorporated NGSS, learning delivery mode (formal, nonformal, informal), and transfer of learning to examine the participant's understanding, learning, and implementation of NGSS to teaching practice.

The research questions for this study focused on three issues: research question (RQ) 1) NGSS understanding, RQ 2) learning format or delivery mode, and RQ 3) transfer of learning. Figure 2 provides a visual of the relationship between the research questions and the systems or structures that contributed to the analysis of the study data.

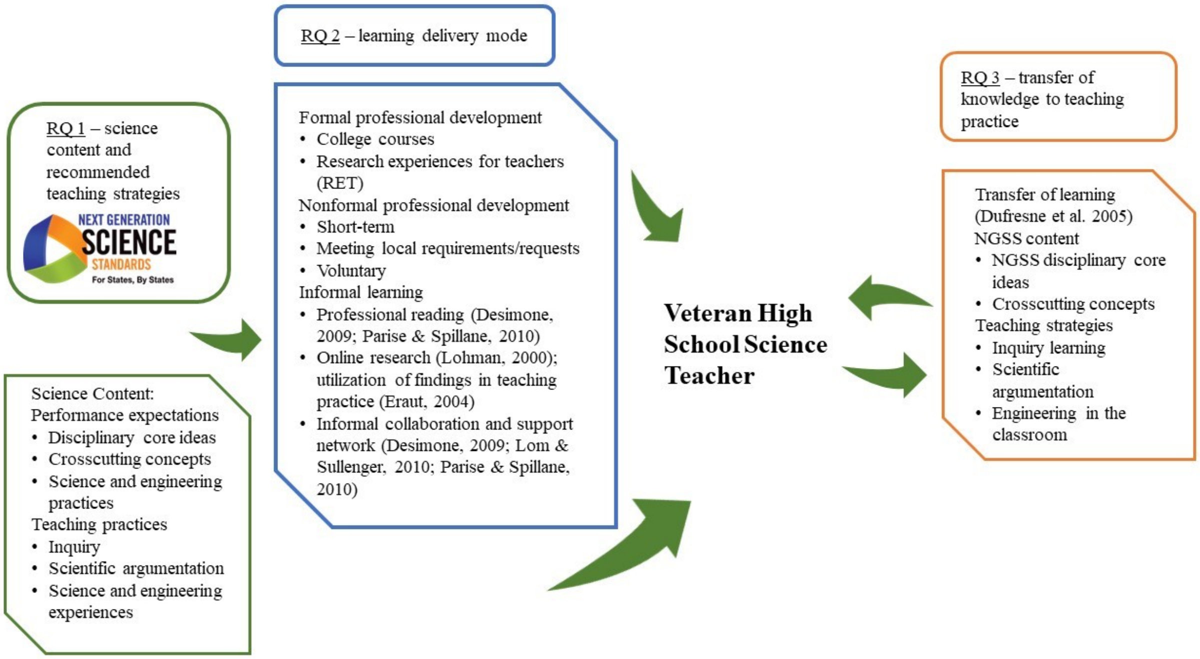


Figure 2. Conceptual framework as applied to this study's research questions. NGSS image from Achieve, 2016.

Research question one addressed NGSS understanding and provided information about the participants' understanding of NGSS structure, content, and implications. Professional development mode, or delivery method, was addressed in research question two. Participants described learning experiences that have influenced their understanding of NGSS; these stories were analyzed for the influences of formal PD, nonformal PD, and informal learning on participants' NGSS understanding and classroom practice. Transfer of learning, research question three, relied on the conceptual framework of transfer of learning to explore the participants' application and interpretation of NGSS professional development and learning in classroom practice.

Transfer of learning was examined using Dufresne et al.'s (2005) three aspects of transfer: 1) the process of transfer of learning – using and applying knowledge, 2) the dynamics or context – selection and utilization of existing knowledge in a specific context and the constant adjustments, observations, in response to actions and expectations and 3) the validity and viability of transfer — actions and information may not have been completely transferred. Study data, particularly a comparison of interviews transcripts with observation and document data, provided information about the application of learning and dynamics of transfer. Validity and viability of transfer was harder to assess, but, as with Smith and Lindsay (2016) and van Duzor (2012), participant reflection and interview responses supported an evaluation of that facet of transfer of learning.

Case Study Design

This qualitative research was a multi-case study with three participants. Creswell (2013) defines case study research as an "approach in which the investigator explores a real-life, contemporary bounded system or multiple bounded systems over time, through detailed, in-depth data collection involving multiple sources of information" (p. 97). Each participant was a case in this multi-case study. Each participant was a unit of analysis with attention on the participant's experiences with NGSS understanding, learning, and transfer of NGSS knowledge to classroom practice. Yin (2009) advises that a clear understanding and description of the unit of analysis is critical to case study. This study was not interested in all facets of the participant's teaching and professional development, only those aspects that were relevant to understanding how the participant described his or her NGSS understanding, learning, and transfer of NGSS knowledge to classroom practice.

This was a multi-case study with three participants. This type of study, a multiple case study, examines one issue with multiple cases to represent an array of experiences (Creswell, 2013). As with most case studies, generalization was not a goal for this study (Hays, 2004). The use of multiple participants allowed for comparison of experiences between and within the cases (Yin, 2009).

Participant Selection

Participant selection was criterion based (Creswell, 2013); a convenience sampling technique was used (deMarrais & Lapan, 2004). Study participants were "accessible, willing to provide information, and … shed light on a specific phenomenon or issue being explored" (Creswell, 2013, p. 147). Although this sampling technique has disadvantages, self-selection by the participants limits generalizability and each participant has his or her own motives for participation, the time required of the participants and their willingness to share were more critical to a successful study.

For this study the participants were selected based on specific criteria: he or she was willing to participate in the research and had at least five years teaching secondary science. As this study focuses on NGSS implementation, each participant was currently teaching a high school science class requiring application of NGSS: life science, physical science – including physics or chemistry, or earth and space science.

Science teachers at high schools within a 75-mile radius of the researcher's location were identified through school websites. Individual emails, Appendix A, were sent to teachers. The first three volunteers at three different research sites who were accessible during a common time frame were selected to participate. Each of those building administrators was contacted and granted permission for the study to be conducted with their teacher and in their classroom.

Research Sites

The study was conducted primarily at the participants' school assignments – suburban Midwestern public high schools. Each participant taught at a different high school. Participants had the option of choosing an alternate location for the interview component of the study. Those alternate locations provided for uninterrupted conversations. Two of the three participants elected to hold the first interview at a public location; all other interviews and observations were done in the participants' classrooms.

Pilot Study and Bracketing Interview

After proposal defense and Institutional Review Board (IRB) approval, a bracketing interview and pilot study was done. As a current high school science teacher in a state that has adopted NGSS as the state science standards, I am expected to incorporate NGSS in my lessons, teaching practices, and assessments. I am learning about NGSS, as these participants have, through PD. My experiences with NGSS PD and my implementation of NGSS to my teaching practice influenced my expectations from this research study. A bracketing interview allowed me to see my experiences in a format similar to the data I will gather during this study. During the bracketing interview a trusted colleague used the semi-structured interview questions to interview me about my experiences with NGSS learning and implementation. My responses to the questions helped me realize some of the “perspectives your own experience provides” (Kramp, 2004, p. 115). The bracketing interview transcript contributed to a greater awareness of my subjectivities and how they might influence this research study.

A pilot study is a formative test to evaluate the data collection methods and research design prior to the full-scale study (Yin, 2009). A pilot study was conducted with a science teacher that matched the selection criteria for the study: a veteran high school science teacher with at least five years experience teaching secondary science who was teaching a physical science, biology, or earth science course. The same procedural steps were taken in the pilot study that were anticipated in the full study: presentation of study procedure and participant orientation, IRB consent form, semi-structured interview using initial questions included in this proposal, a classroom observation, and document review. Following these steps allowed for an assessment of the value of the language and direction of the interview questions and observation structure. Several questions were altered to remove vague language and elicit participant responses that were more closely aligned with this study’s research questions. The observation protocol was modified to include lists of the cross-cutting concepts and science and engineering practices so those could be quickly noted during classroom observations and linked to specific observations.

Protection of Human Subjects

Educational research, especially case study, is a collaborative effort between the researcher and the participants. This collaboration can create a vulnerable situation, particularly for the participants (Kim, 2016). Approval for research was obtained from the appropriate Institutional Review Boards (IRB) prior to research beginning. The IRB reviewed the study “for their potential impact on and risk to participants" (Creswell, 2013, p. 152) and found that the proposed methodology presented minimal risk to the participants. Each participant was asked to read and sign, after a discussion of the study requirements and expectations, an informed consent form (see Appendix B). Each participant signed the consent form prior to data collection. Because this study took place in high schools, I obtained permission from each school district and building administration before I conducted research. Those approvals were in addition to the academic institution IRB.

Reciprocity

No monetary or tangible items were given to study participants during this study. After the study I offered to share resources on NGSS learning and implementation in the science classroom that I gathered during this research process.

Ethical Practice

I established and maintained regular communication with the study participants. Before individuals agreed to participate in the study, I explained the study's research purpose and questions. I provided a brief personal and professional history, making sure to indicate my subjectivities concerning NGSS learning and implementation. After all questions were answered I confirmed the teacher's willingness to participate in the study.

I was respectful of the participants' voices throughout the data collection and analysis. I conducted member checks following each interview. Consistent with deMarrais and Lapan (2004), I removed or modified material if a participant was not comfortable with my representation of his or her experiences. Throughout the study I maintained participant privacy. Interviews were conducted at a location of the participants' choice — either the participants' classrooms or in alternate location selected by the participant. Pseudonyms were selected by the participants and utilized throughout the study. Participants had the right to withdraw from the study at any time without explanation.

Observations were conducted in the participants' classrooms. These observations focused on the participants' actions and interactions. No recordings were made during the observations. No identifying notes were made of any individual other than the participant. These efforts were made to ensure confidentiality and minimize risk to all involved in this research study.

Data Collection Methods

Data were collected through participant interviews, classroom observations, field notes, and document analysis — including lesson plans and curriculum resources. Each participant took part in the research activities in the following order: interview #1 and document submission, observation #1, observation #2 and document submission, and interview #2. For one of the three participants interview #2 occurred prior to observation #2 because of that participant's availability. The study lasted approximately sixteen weeks; participants were actively engaged for three to four weeks of that time. A timeline is provided in Appendix C. Table 1 contains an overview of the quantity of raw data collected during the study.

Table 1 *Data Inventory*

Source of data	Number of pages	Number of pages total
2 interviews with each participant (first interview 35-50 minutes; second interview15-20 minutes)	25 pages per participant (average)	3 x 25 = 75 pages
2 50-minute observations with each participant	8 pages per observation	3 x (2 x 8) = 48 pages
Class materials/handouts from each participant	18 pages per participant (average)	3 x 18 = 54 pages
3 member checks	2 pages per member check	3 x (3 x 2) = 18 pages
Journal reflections	5 pages per week, 16 weeks	5 x 16 = 80 pages
	Total pages	275 pages

Interviews

This case study involved an exploration of teacher professional learning and transfer of learning in the context of NGSS. Those perceptions are unique for each participant. Interviews provided the researcher the opportunity to learn about the participant's values and experiences in the participant's own words (Kim, 2016; Schwandt, 2015). Much of the data for this study were gathered from interviews with the participants.

The first interview for each participant took place in a location of his or her preference. Two of the three participants elected to hold the first interview in an alternate location that offered a relatively private location that was conducive to audio recording. All other interviews took place in the participants' classrooms. The first interview for each participant lasted 35-50 minutes. The second interview for each participant was shorter, lasting 15-20 minutes each. The interviews were audio-recorded; I transcribed the recordings.

Each of the interviews was semi-structured dialogues. Semi-structured interviews are a common source for data in qualitative inquiries (deMarrais & Lapan, 2004; Kim, 2016). Hoping to elicit extensive stories and multilayered responses, I prepared several questions that focused on the participants' experiences and beliefs about NGSS learning and NGSS implementation for the first interview. The questions for the first interview are listed in Appendix D. Questions for the second interview were prepared after a review of the first interview transcripts and the field notes from the first observations. The second interview was used to clarify participants' responses to some of the first interview questions and to explore some of the teaching practices noted during the observations. Several questions were used with all three participants.

1. What has contributed to your understanding of the Next Generation Science Standards?

2. How would you describe NGSS to someone who has never heard of it?
3. How do you decide what to include and what to exclude when you are planning lessons for your classes?
4. How have your teaching practices changed since the implementation of NGSS?

Appendix D contains a table with the three data sources and their alignment with the corresponding research questions.

Participant Observations

Interviews can provide the participant's perspective on his or her understanding of NGSS and classroom teaching practices. Interviews cannot provide specific details on the participants' behaviors in the classroom. Observing the participants interacting in the classroom provided a more complete picture of the participants' experiences. Observations provide the researcher with the opportunity to view the participant's activities, interactions, conversations, and behaviors (Creswell, 2013).

Two 50-minute observations were done in each participant's classroom. Field notes and drawings were made during each observation. Those notes focused on the participant's actions and words with the class. Information about the classroom setting, materials and equipment provided, the classroom activity, and any significant attitudes or discoveries were recorded. The observation protocol is available in Appendix E; Appendix F includes an observation field notes template. These observations allowed me to note key actions and comments that might be overlooked or considered unimportant to the participant. During one observation the teacher deliberately gave an incomplete list of necessary lab equipment to students so the students would have to realize they needed length measurements and a tool to obtain those measurements. This was not reflected in the student handout provided by the teacher. During another observation a teacher was leading a conversation about heating and cooling water. He linked that conversation to cause and effect, a NGSS cross cutting concept. The field notes added to the verbal picture and stories provided from the participant interviews.

Document Analysis

Artifacts can provide a more complete picture of an experience and "excavate further stories from our participants" (Kim, 2016, p. 177). Participant professional development resources and course documents were the artifacts of interest in this study. At each interview and each observation the participants were invited to provide documents pertinent to this study. A description of the document analysis protocol is included in Appendix G. These documents included anything that might provide information about NGSS PD, NGSS learning, and NGSS instruction. Classroom handouts, course textbooks, lesson plans, and grading rubrics were also requested. These documents provided a third source of information to augment the participants' descriptions of the use of inquiry, science and engineering practices, and scientific argumentation in classroom instruction and assessment and the classroom observations. When available, student products were ~~also~~ reviewed for comparison with assignment instructions and grading rubrics.

Member Checks

Member checks allow research participants to provide feedback to researchers during the data collection and analysis process (Schwandt, 2015). The participants were given the opportunity to review interview transcripts and observation field notes after data collection. The transcripts and observation field notes were emailed to each participant; as recommended by Stake (1995), the participants were invited to review the documents and provide comments, clarification, or corrections. Participant comments and concerns were addressed, if presented, before this document was finalized.

Data Collection Summary

In an effort to gather a variety of material to provide information about the array of professional development experiences and teaching practices utilized by the study participants, several types of data were collected. Each participant was asked to participate in two iterations of semi-structured interview and classroom observation. Interview and observation, in some circumstances, occurred on the same day for a participant. The first interview and observation were used to inform questions for the second interview. The pattern of interview-observation-observation-interview allowed the participant to explain or clarify any questions that might arise after an initial review of the interview transcripts and observation field notes. At each interview and observation participants were encouraged to provide documents related to NGSS PD or classroom instruction. Following each interview and observation each participant was given the opportunity to member check the transcript and/or field notes.

Data Management

Care must be taken with all research data. Creswell (2013) suggests that researchers consider data backup, data inventory, and participant anonymity. Implicit in the guidelines is a need for protecting the confidentiality of all participants. Each participant was given the opportunity to select a pseudonym. That pseudonym was used for all data management.

Interviews were recorded on two digital devices; files were transferred to an external data device for long-term storage. I transcribed the interview recordings to Word documents prior to analysis. All other digital media and files are stored on a password-protected computer and backed up on an external storage device that is also password protected. All paper documents including signed participation agreements are stored in a locked cabinet. All research records, including digital and paper files, will be stored securely for at least five years from the completion of this study.

Data Analysis

The interview transcripts and field notes were transcribed into Word documents. The data - interview transcripts, observation notes, and documents provided by the participants - were uploaded to a qualitative analysis software program: NVivo (QSR International, 2018). The software served as an organizational tool during coding and data analysis.

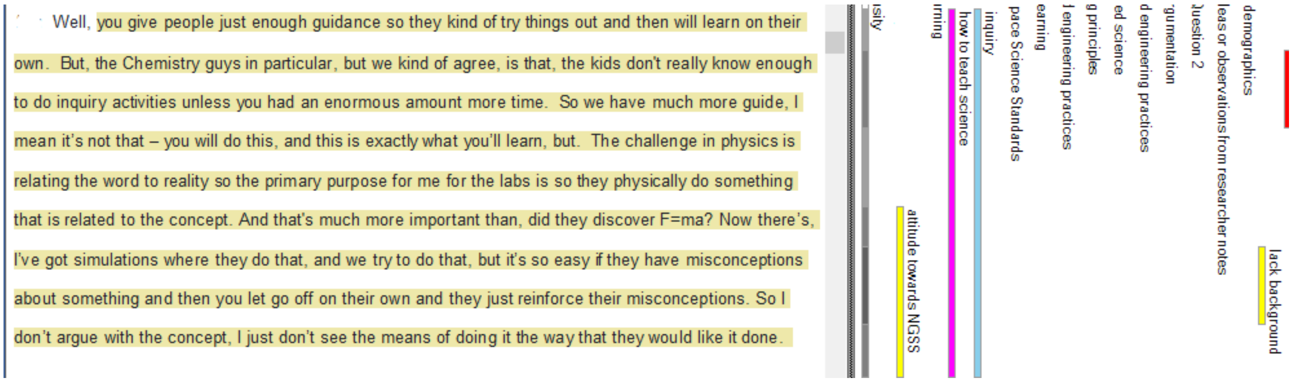
Saldaña (2016) suggests two or more cycles of coding for any qualitative data set. Provisional coding was used for the first cycle of coding. Provisional coding starts with "a predetermined start list of codes prior to fieldwork" (Saldaña, 2016, p. 168). This project's literature review and the conceptual framework were used as a source for the provisional codes: professional development, formal learning, informal learning, transfer of learning, NGSS. Additional codes were added during data analysis: inquiry, science and engineering practices, scientific argumentation, and how I learned science.

The NVivo software facilitates multiple layers of coding and organization. I used values coding as a guide during a second cycle of coding. Values coding allows for data analysis that acknowledges "a participant's values, attitudes, and beliefs" (Saldaña, 2016, p. 131). Participants' values were significant to the participants' learning and transfer of that learning to the classroom. Figure 3 represents a portion of the Nvivo codebook that includes examples of provisional coding — formal learning, informal learning, nonformal learning, professional development, crosscutting concepts, and science and engineering practices — and values coding

— applicable to teaching practice and waste of time. Figure 4 is a small portion of an interview transcript and the associated codes that were identified during the data analysis.

Name	Description	Files	References
Research Question 2		5	12
applicable to teaching practice	values code - comments that suggest teacher found experience important or applicable to classroom practice	6	24
formal learning	provisional code - includes learning experiences with a specified curriculum that leads to educational credits, an academic certificate, or a degree	1	6
informal learning	provisional code - learning that occurs during or following routine, daily activities; can include professional reading, observations, peer collaborations, research, reflection	8	36
nonformal learning	provisional code - any professional development that has a structure or content specified by an organization rather than the individual; does not include formal learning experiences	5	23
professional development	provisional code - any professional development experiences that include formal classes, other trainings, nonformal conferences or workshops, or informal learning	7	55
waste of time	values code - participant, by tone or language, suggests training or resources did not add to classroom practice	4	26
Research Question 3		2	2
crosscutting concepts	Provisional code - NGSS specified: patterns, cause and effect (mechanism and explanation, scale, proportion, and quantity, systems and system models, energy and matter (flows, cycles, and conservations),structure and function, and stability and change	9	36
Science and engineering practices	Provisional code - 8 practices described by NGSS: asking questions and defining problems, developing and using models, planning and carrying out investigations, analyzing and interpreting data, using mathematics and computational thinking, constructing explanations and designing solutions, engaging in argument from evidence, and obtaining, evaluating, and communicating information	9	38

Figure 3 A portion of the Nvivo codebook that includes provisional and values coding identified during data analysis.



Well, you give people just enough guidance so they kind of try things out and then will learn on their own. But, the Chemistry guys in particular, but we kind of agree, is that, the kids don't really know enough to do inquiry activities unless you had an enormous amount more time. So we have much more guide, I mean it's not that – you will do this, and this is exactly what you'll learn, but. The challenge in physics is relating the word to reality so the primary purpose for me for the labs is so they physically do something that is related to the concept. And that's much more important than, did they discover F=ma? Now there's, I've got simulations where they do that, and we try to do that, but it's so easy if they have misconceptions about something and then you let go off on their own and they just reinforce their misconceptions. So I don't argue with the concept, I just don't see the means of doing it the way that they would like it done.

Figure 4 A portion of an interview transcript with its associated codes.

The codes identified throughout the layers of analysis were gathered and combined into categories, which led to the themes presented in the subsequent chapters of this document. For example, codes of inquiry, waste of time (value), and student comprehension combined into a category of usage of inquiry learning experiences in the science classroom. Each of the three cases presented in this study provided category information about inquiry learning in the science classroom. Those categories combined for a theme about inquiry learning that was incorporated multiple opinions about the effectiveness of inquiry learning in high school science classrooms.

The portion of the transcript included in Figure 4 represents part of one participant's description of his experiences with inquiry learning in the classroom. That content, combined with observation field notes, suggested that this teacher, while avoiding inquiry learning experiences in the classroom, still incorporated some components of inquiry during laboratory activities. This overlap and discontinuity of codes and categories between and within the participants' experiences was of particular interest during the data analysis.

Researcher Background

A researcher must be mindful of his or her own subjectivities. Peshkin (1988) argued that awareness of these subjectivities allows the researcher to "learn about the particular subset of personal qualities that contact with their research phenomenon has released" (p. 17). My experiences with science instruction and NGSS contribute to my researcher subjectivities and influence my choices throughout the research process.

I completed my formal training as a high school science teacher more than 25 years ago. At that time, science teaching was focused on content knowledge. Students were expected to practice the science skills associated with that knowledge and memorize associated facts. Instruction was primarily delivered through lectures. Students were provided with detailed laboratory instructions for experiments that substantiated science “facts”. That is how I learned science in high school and college; that is what was reinforced in my teacher education courses.

I was not active in the secondary science classroom for many years. When I returned to the high school science classroom in 2015, I realized that, while I was confident about my teaching skills and science content knowledge, much had changed about science education. What began with the nation focusing attention on science education with the publication of *Science for all Americans: Summary, Project 2061* (Rutherford & Ahlgren, 1990) had continued with the Next Generation Science Standards (NGSS) (2015). These and other reports stressed the need for increased scientific literacy and critical thinking skills (Rutherford & Ahlgren, 1990). NGSS (National Research Council, 2013a, 2015) incorporated inquiry, science and engineering practices, and scientific argumentation through all levels of K-12 instruction to allow students to build their own science knowledge. Reading these science standards is relatively simple. Determining what they mean to my teaching is not so straight-forward.

My home state adopted NGSS as the state science standards shortly after NGSS was published in 2013. Over the last three years the science teachers in my school district have met to discuss what NGSS means to our science curriculum. For the middle and high school standards, NGSS does not dictate when in the grade levels content must be covered, those decisions are left to local policy. As a district, together with our building and district administrations, the science teachers were asked to determine what content and standards would be addressed in each science course, and then to plan specific activities to incorporate inquiry, science and engineering practices, and scientific argumentation.

Two years later, the district science departments are still engaged in this process. Deciding which standard fits best in which of our existing science courses was fairly easy, but some standards were not currently addressed by our district's required science courses. That prompted discussions of how our science department was going to offer instruction on all standards to all students. Placing standards into courses was the easy part. The much more difficult task is for the classroom teacher, hopefully with the combined departmental experience, to decide how to teach science and offer authentic and realistic inquiry and engineering learning opportunities. That is something we struggled with during our department meetings, and something that will continue to present challenges to most science teachers.

As I learn more about NGSS and think about the way students can and should learn science, I thought about my high school and college instructors. They taught me as they had been taught. I followed that pattern with my classes until relatively recently. Other older, "veteran" high school science teachers may not be motivated to update and innovate student learning opportunities. The standards and learning expectations explicit and implicit in NGSS demand that all science teachers utilize science and engineering practices in instruction and assessment. That will not be an easy transition for many veteran high school science teachers.

Trustworthiness

As described by Lincoln and Guba (1985), trustworthiness allows the reader to judge "the quality, or goodness, of qualitative inquiry" (Schwandt, 2015, p. 308). Four ideas are central to this description of trustworthiness: credibility, transferability, dependability, and confirmability (Guba & Lincoln, 1989; Lincoln & Guba, 1985). This research methodology was designed to address each of these concerns.

The credibility of this research study is dependent on the alignment between my participants' experiences and my representation of those experiences in this report. Member checks are an important tool when preparing a credible research report. Research findings are transferable in case studies only if the reader is provided with enough detail about the participant(s) and the study to assess comparability with other cases. Research is dependable when there is visible and documented logic to the study. A well-written methodology provides this information. The final component, confirmability, links the findings and interpretations to the research data. Again, as with dependability, careful explanation within this report is important to convincing the reader that the data did support the findings.

Many of the research components already mentioned in this methodology were important to establishing trust with participants. The bracketing interview illuminated my subjectivities regarding inquiry-based learning. I shared those subjectivities with the study participants prior to the first interview. Member checks allowed the participants the opportunity to review and confirm study findings (Schwandt, 2015). I listened deliberately and carefully to the participants' comments during member checks and made modifications to the documentation as necessary (deMarrais & Lapan, 2004). Peer debriefings were also utilized in an attempt to maintain candor and trust. In peer debriefing I asked trusted academic colleagues to review the direction and progress of the research study with me (Schwandt, 2015) in an effort to ensure clarity, rigor, and integrity with the project.

Study data came from several sources: interviews, observations, and documents. Multiple data sources allow for triangulation of findings between and among those data sources (deMarrais & Lapan, 2004; Schwandt, 2015). Yin (2009) advised that "any case study finding or conclusion is likely to be more convincing and accurate if it is based on several different sources of information." The three sources of data used in this study allowed for the codes and themes to be visible in multiple situations and increased the trustworthiness of this study's findings.

These efforts were made in an attempt to provide an authentic representation of the participants' experiences with inquiry-based learning in the classroom. Readers will interpret the findings and narratives within the context of their subjectivities and experiences. My task, as the researcher, was to provide a representation that is true to the participants' understanding of their experiences.

Chapter Summary

This qualitative case study examined the experiences of veteran high school science teachers with respect to their Next Generation Science Standards (NGSS) learning through formal, nonformal, and informal experiences and explored how that knowledge was transferred to classroom practice. Qualitative case study allowed for the recognition of the influence of each participant's pre-existing knowledge, teaching experiences, and many other factors. The theoretical framework of symbolic interactionism respected the development of meanings by the researcher-participant team which fostered an authentic representation of the participant's experiences with NGSS and transfer of NGSS learning to classroom practice.

Participants were experienced secondary science teachers currently teaching a physical science or physics class. Participation was voluntary and confidential. Appropriate Institutional Review Board and research site permissions were obtained before any data collection occurred.

There were multiple data sources: semi-structured interviews, classroom observations, and participant provided documents. These data sources and researcher notes were transcribed and organized with Nvivo qualitative software. Multiple iterations of data coding suggested themes that provided answers to the research questions about the participants understanding of NGSS, learning about NGSS through formal, nonformal, and informal experiences, and how that learning is transferred to classroom practice. All three primary data sources — interviews, observations, and documents — contributed to a complete picture of the participants' experiences with NGSS. The interviews allowed the voices and words of the participants to be heard. Observation and document data offered support for the participant's perceptions or suggested contradictory ideas and provided additional information about transfer of learning to teaching practice. Together, the three data sources were important for data source triangulation and provided reinforcing information that presented a more complete representation of each participant's experiences with NGSS learning and transfer of NGSS to classroom practice.

Chapter 4: Analysis of the Data

The purpose of this qualitative multi-case study was to explore how veteran high school science teachers describe NGSS, how those teachers describe their formal, nonformal, and informal learning experiences, and how those teachers are transferring NGSS knowledge and the NGSS goals of inquiry, science and engineering practices, and scientific argumentation to the classroom. This study examined the experiences of three veteran high school science teachers.

Research Overview

This study used the conceptual frameworks of NGSS, learning delivery mode — formal, nonformal, informal — and transfer of learning to answer the following research questions.

1. How do veteran high school science teachers describe NGSS?
2. How do veteran high school science teachers describe their NGSS-focused experiences according to the classifications of formal, nonformal, and informal learning?
3. How do veteran high school science teachers transfer knowledge and modify teaching practices and science content as they incorporate NGSS specified inquiry, science and engineering practices, and scientific argumentation?

Three high school science teachers from three suburban high schools participated in this research study. The study interviews and observations were done near the end of the spring semester. Each participant was interviewed two times, allowed two classroom observations, and submitted professional development and/or classroom documents for analysis. Each participant was a case in this multi-case study. Each case was analyzed with the conceptual frameworks of NGSS, learning delivery mode, and transfer of learning. A cross-case analysis follows the individual case presentations.

Participant Demographics

There were three participants in this research study: two male, one female. Each participant is identified in this report by a pseudonym. All three participants taught science at a different large suburban high school; student populations for the three schools ranged from 1300 to 1900 students. Other demographic information about the participants is presented in Table 2. All three of the participants earned their teaching certificate through alternate pathways; each had a professional career in another field prior to entering the classroom as a teacher. All three had completed a master's degree in education. These common characteristics of the participants were coincidental. The research population was obtained through convenience sampling, participant demographics were not known prior to the beginning of the study.

Table 2 *Participant demographics and NGSS PD description*

Case	Course taught during study	Number of years teaching science	Number of years teaching science with NGSS	Participant Quote describing NGSS PD
Jim	Physical science	15	5	"It seemed like every PD the first four or five years I was in the district was trying to show us and introduce us to NGSS and the cross cutting concepts."
Andy	Physics	15	5	"So we got no textbooks, we got no test support. We got no, no – here's some activities or labs, or anything like that you could do."
Jessy	Physical science	7	1	"I spent this year kind of trying to figure out what I have taught in the past, what the district requires me teach, and how those Next Generation Science Standards align with all of that."

Each participant represents a case and unit of analysis. Each case will be presented individually, followed by a cross-case analysis.

Case 1: Jim

Jim had been teaching high school science for 15 years, all in the state of Kansas. Jim has a bachelor's degree and worked in industry before earning an alternate teaching certificate and beginning his teaching career. Jim continued his education and completed a master's degree in education after he started teaching

Jim's classroom, see Figure 3, had a large teacher desk at the front of the room; the wall behind the teacher desk was covered with a large white board. There were six tables that could seat four students each. Lab stations were on the back and side walls. The lab stations were not in use during the first observation. Each x in Figure 3 represented a student.

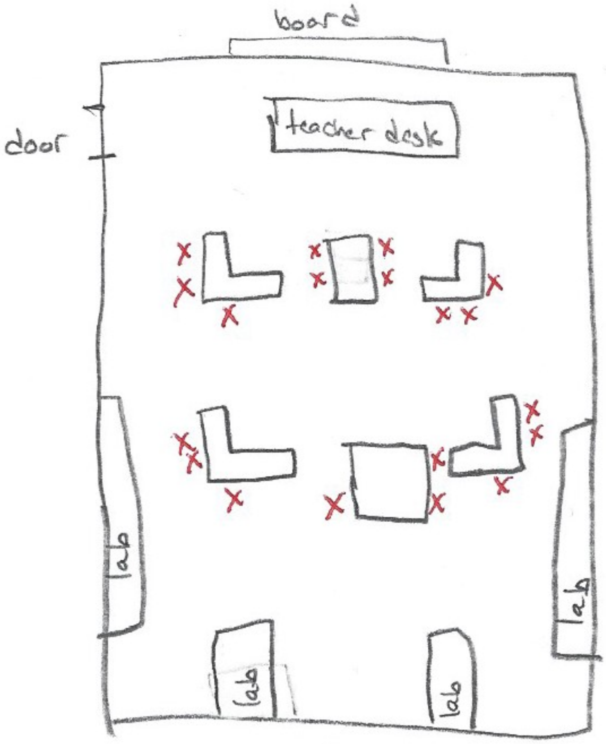


Figure 5 Jim's classroom - observation 1

Jim greeted students by name as they entered the classroom. Most conversations were brief. Many students plugged cell phones into outlets on the side counters. The cell phones stayed there, unused, until Jim gave a brief break in the middle of the class. Jim directed one student to a specific seat. Jim's conversation with this student was more extended. Jim reassured the student that it was okay if he did not understand all of today's material because he had been gone for several days; he should do his best and they, Jim and the student, would see where things were at the end of the semester. By the time the bell rang to start the class there were 19 students and a para-professional teacher in the classroom with Jim.

Immediately after the bell rang signaling the beginning of the class period, Jim noted which students were missing from the classroom. The next four or five minutes were spent with student responses to Jim's prompt: "Any good stories?" This was obviously part of the regular routine as students readily volunteered brief reports: "I went to a family wedding", "my mom got back from her trip", and "I'm caught up on all of my classes." Students were respectful and listened to one another. Jim, and the class, celebrated with the student who had caught up on her coursework.

As this was a 90-minute long class, Jim advised the class that they were breaking the day into three or four chunks — depending upon how they moved through the activities. The general plan was displayed on the board: retrieve and present in groups, brain break, heat, and final exam study guide. For the first activity Jim split the class into small groups of three or four students; each group was given one of five topics: atoms, ions, periodic table, compounds/molecules, and reactions/equations. The groups were given 15-20 minutes to "retrieve" their assigned topic. Jim's classes have been drawing "retrievals", 2-dimensional representations of ideas or concepts that could include words, pictures and/or equations, all year. He advised the groups that all the retrievals would be constructed on the board as one product after the work time. Jim directed the students to a guiding list of terms written on the board.

With Jim's assistance and encouragement, the groups constructed a "retrieval" on the board linking the five assigned topics. A representative from each group presented the group's section of the display to the class. These topics were the major topics covered during the second semester of the physical science class. Jim advised the students that they would continue to practice retrieving the ideas over the next few weeks in preparation for the final exam.

Students returned to their original tables after a short break to use the bathrooms or check phones. Jim asked the students to gather paper and something to write with as he introduced the idea of heat. For the next twenty minutes Jim discussed ideas of heat, temperature, and movement with the students, often linking new concepts and terminology to first semester content and real-life examples. The remainder of the class period was spent reviewing questions on the final exam study guide students received earlier in the week.

My second observation of Jim's classroom occurred approximately two weeks after the first. This was a 50-minute long class period with a different group of 20 physical science students. The room arrangement was the same as Figure 3, but for this class the students used the lab stations around the sides and back of the room for part of the class period. The locations of students during the lab activity are represented by circles in Figure 4; the students were seated at tables, indicated by the x symbols, the rest of the class. As with the first observation, Jim greeted students as they entered the classroom and began class by asking for "any good stories". Students reported on notable events: concerts and movies attended, family visits, and driving experiences. After this discourse Jim directed students to the day's plan: a 30-minute lab followed by final exam review. The words, "I can identify endothermic and exothermic reactions" were written on the board.

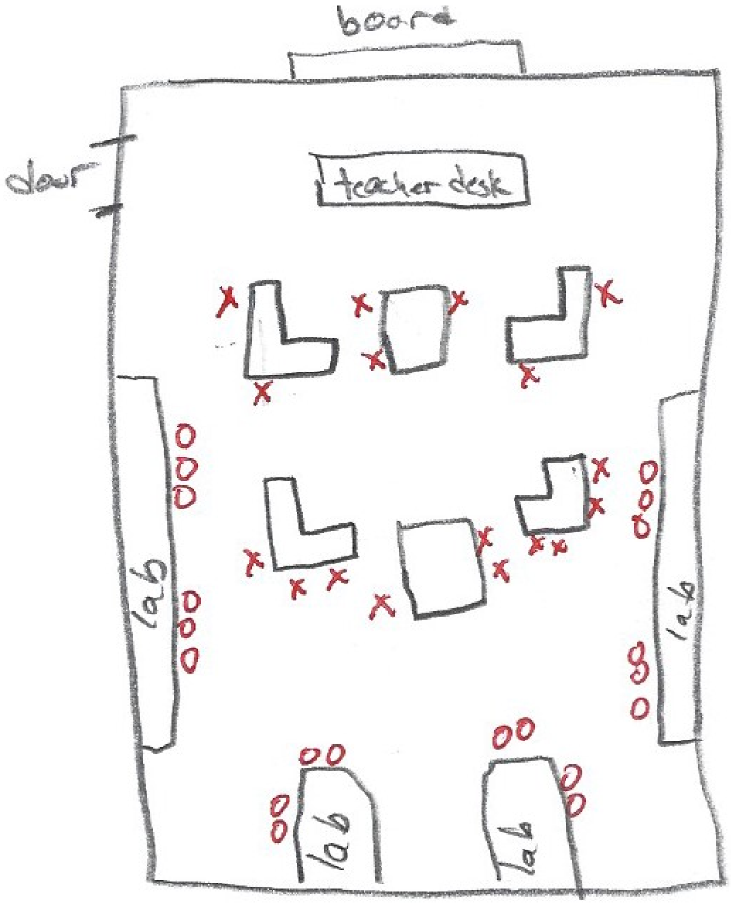


Figure 6 Jim's classroom - observation 2

Jim introduced the lab for the day: Calcium chloride and sodium chloride comparison. Jim reminded students of a similar procedure from the previous week then allowed the groups to move to the lab stations around the room. Students combined calcium chloride with ice water and recorded temperature changes. Prior to combining the substances, students were asked to make a prediction about the temperature of the mixture. They completed a similar activity with sodium chloride and ice water. After all the students completed both procedures, they cleaned up the lab stations and returned to their tables. Jim led a discussion of the students' predictions and the alignment of those predictions with their observations. The last ten minutes of class was spent “retrieving” concepts: ions/charge, periodic table, metals, and nonmetals. Students were invited to post on the board and share with another with the time remaining in class.

The information gathered from Jim’s interviews, documents, and observations have contributed to the findings represented below.

NGSS Description

When asked to describe NGSS, Jim said, “it’s just a road map for how you teach science in the most effective way possible. It’s research based, to me it’s just — here’s the right way to teach the subject.” Jim utilized many of the terms associated with NGSS during our interviews: performance expectations (PE), phenomena, inquiry, and engineering. Jim noted, “I think assigning the performance expectations makes it easier to see what we’re shooting for. I use them a lot for my objectives every day and my learning targets.” Concerning phenomena, Jim commented, “Give the kids something they’re interested in, get them doing stuff that’s hands-on, and then back it up with whatever you need as far as worksheets and lectures.” Jim recognized the importance of student engagement with content as a precursor to learning. Referring to NGSS and its influence on science education, Jim frequently returned to the phrase, “It’s how science should be taught.”

Jim considered NGSS “the right way to teach the subject” and “an improvement or at least documentation on what the right way to teach the subject is.”   Jim “didn’t see them [NGSS] as anything revolutionary.” He did not find it necessary to refer to the standards during lesson planning or instruction. “I can’t tell you that I look at those standards at all. I looked at them when I compared them to what we teach here for physical science and said that will give me some good approaches to this.” Jim relied on the district course objectives to determine the content in his physical science course. The NGSS material was a resource: “I pick and choose among the standards and what I know I can teach kids well and what they’re gonna learn.”

NGSS Professional Development

For the last several years much of Jim’s district-provided PD focused on NGSS. “We’ve been talking Next Gen Science Standards almost since I got here seven, eight years ago.” One of the science teachers involved in developing NGSS was on staff with Jim’s school district, so the district had access to documents and other information during the development and adoption process. “It seemed like every PD the first four or five years I was in the district was trying to show us and introduce us to NGSS and the crosscutting concepts and all those things.” Despite the quantity of NGSS PD, Jim noted, “I didn’t find a lot of the professional development to be something I could leave and go do in my classroom.” Jim did acknowledge value in NGSS — “it’s how science should be taught.”

Jim noted the importance of choice in PD. Commenting on time he spent in district-provided PD during the school year compared with a PD experience he chose: “I probably could have skipped all the PD this year. Which would have been better.”

Formal professional development. Jim identified a formal learning experience as a dominant factor in his current teaching practice. Jim elected to spend two weeks last summer taking a college course with a few of the other science teachers from his building. “I chose to go to it, which probably made it more valuable to me because, as we all know, if you choose to be there you’re going to get more out of it.” The course, using Brown, Roediger, and McDaniel’s *make it stick* (2014) as a foundation, revolved around the brain and how people learn and retain information. Jim remarked, “it’s a different way of learning and teaching” and “it was career-changing, to take that class.… And life-changing for 129 kids, I don’t mind saying it that way.”

Jim found this formal learning experience remarkably significant to his science teaching – not because of NGSS, but because he found the ideas and techniques significant to his efforts to help his students learn.

Nonformal professional development. Jim's district and school incorporated nonformal PD throughout the school year ranging from entire PD days to weekly professional learning community (PLC) meetings. The full day PD varied from large group formats to smaller offerings. Although both formats had little value for Jim, given options, he would select the small group experiences.

> I hate the large group activities. I hate being in a room with all of the high school science teachers watching somebody play a video or whatever the district has put together to tell us how this is supposed to be done.

Jim's attitude towards large group PD was apparent from his comments. The PD content did not improve his outlook on the experience. "We did some phenomena-based stuff and had some experiences. But to me it was – yeah, so what? I get it. I understood this already. I didn't need to spend a half a day doing this."

Jim's feelings towards smaller group learning experiences were more positive, but still offered conflicting comments. "I much prefer when we break into groups by what we teach. We need to be together as a group more because that's a unique set of kids [the physical science students]." At another point during our interview Jim expressed frustration with this format — he was the only physical science teacher in his high school; when breaking into subject areas for PLC he was assigned to chemistry or physics, depending on the week. Jim found those conversations unhelpful because of the differences in content and student populations in the classes. Looking forward, Jim expressed optimism for the upcoming year. The school would be adding two more sections of physical science so there would be a second physical science teacher.

> I'm really looking forward to next year when I'll have a colleague teaching a couple sections of this, the hours I don't. Because I think she's going to be a really good partner. So that's only going to make me better too.

Taken together, Jim's comments suggested that his frustration with the small group learning activities available during PLC was not because of the format, but because there were no other physical science teachers in the building.

That idea was reinforced by other remarks Jim made during our interviews: "the best learning I get out of that, in the small groups, is by stealing or borrowing from my colleagues" and

> I have plenty of opportunity to say where I can see something somebody did and like or I can totally take that and use that. Which is, to me, that's the more valuable thing. We don't get those nearly often enough, for my taste.

Jim appreciated the exchanges available during small group meetings; he was frustrated when it did not fit his subject content or student population.

Informal learning. Jim credited his peers as positive influences on his teaching practices. "I've gotten better as I've met good teachers and mentors." He attributed his use of retrieval to a small group of his science teacher colleagues in his building. They attended the college course as a group. Each member of this small group of science teachers used a version of retrieval for student instruction and assessment. Although the products were different for each teacher, Jim found the support of his colleagues important to his success with the teaching practice.

Jim considered the time spent collaborating with colleagues more beneficial to his teaching than other time spent in PD. Jim was the only physical science teacher in his building. In the future there will be additional sections of the course, so another physical science teacher will be added to the building. Jim is anticipating the rewards of another teaching for the physical science course. "So I'm gonna steal a number of things from her and I expect I'm going to pass some of this stuff on to her too."

Transfer of NGSS Knowledge to Teaching Practice

Jim does not believe NGSS or NGSS PD had an impact on his teaching practice. He noted, "I don't think it's changed based on NGSS. I've gotten better as I've met good teachers and mentors and especially picked up on how powerful the brain is and making kids own and retrieve their own knowledge." Jim said the largest influence on his current teaching practice was the college course on the brain and learning that led him to retrieval. Jim used retrieval to "story-tell [his] way through the subject"; his students used the same exercise to develop and represent their own understanding of science. NGSS, with its focus on science and engineering practices and crosscutting principles, encourages students to incorporate new ideas with existing knowledge (Duncan & Cavera, 2015; National Research Council, 2013a). Jim described the growth of student knowledge represented in retrievals, "we built it up, brick by brick, all semester." He explained, "they're [retrievals] are all different. Kids do their own. It's their story and when they own the story, they know it."

Jim noted that NGSS is "how science should be taught." His teaching practices regularly utilized NGSS attributes: science and engineering practices and crosscutting concepts were visible in Jim's choices of class activities, instruction, and assessments.

Science content. Jim taught a sophomore physical science course. As he described it, the course was “physics-light first semester and chem-light second semester.” The district physical science scope and sequence statement provided the primary guidelines for the science content Jim included in the course. Jim realized that he did not address all of the NGSS chemistry standards or physics standards in this course: “I pick and choose among the standards and what I know I can teach kids well and what they’re gonna’ learn.”

Jim focused the entire second semester on chemistry topics, with an overarching theme of particles. That content corresponded directly with NGSS performance expectation HS-PS1-1: “Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms” (National Research Council, 2013a, p. 91). The science content and relationships presented on heat, temperature, and phase changes were addressed in NGSS disciplinary core idea PS3.A: “Structure and Properties of Matter” and PS3.B: “Chemical Reactions” (National Research Council, 2013a, p. 92). Despite using the district physical science scope as a guideline, Jim’s physical science course incorporated NGSS performance expectations and disciplinary core ideas in every lesson discussed or observed during this study.

Crosscutting concepts. Crosscutting concepts are common features of all grade levels and science content areas (National Research Council, 2013a). Many examples of the crosscutting concepts were evident during Jim’s classes. The chemistry “retrieval” utilized at least two crosscutting concepts. Student had to understand the atom’s structure and the function of the subatomic particles. Students identified patterns of chemical reactivity and ion formation.

The crosscutting concept of energy and matter in systems was unmistakable during both observations of Jim’s class. Jim introduced the idea of heat and temperature; he related both to the movement of particles. During the second observation the students were doing a lab activity involving energy – observing temperature changes when adding a substance to ice water. This activity allowed the students to explore the idea of energy ideas of exothermic and endothermic reactions and processes. The students also had to consider cause and effect, another crosscutting concept, for the changes they observed.

Jim's instruction of energy and matter in systems and patterns continued after my visits to his classroom.

> I told the kids: next week on Wednesday we're gonna boil water. You're gonna watch water boil. They all looked at me and I said, no, we really are. We're going to graph what's going on with the temperature because I promise you there is a question on that graph on your final. And I don't need to do any more teaching of that once you've built your own graph of it. You'll know what's going on.

Jim's choices of questions and classroom learning activities required students to interpret experiences with a mind to how those experiences fit into the science they know; the crosscutting concepts supported those efforts.

Inquiry. Inquiry learning is any experience that allows the student to ask questions, design experiments, and analyze data (Rutherford & Ahlgren, 1990). Jim, with the activities he incorporated in class and the questions he posed during instruction, afforded students many opportunities to question and explore scientific ideas. "Give them something, get them interested in it, let them start playing with that and that can drive them into wanting to know why it does what it does" guided Jim's choices in learning activities.

Jim frequently linked science content to routine experiences during class instructions, encouraging students to ask questions about those routine experiences. During a class discussion on heat Jim asked the students why they heated the water used to make macaroni and cheese. Most, if not all, of the students in the classroom had some experience with boiling water for pasta. Jim encouraged them to reflect on that common activity and suggest questions about its role in food preparation and the science behind that role. Jim noted: “I want the kids to pose the question themselves or come up with it as to what is going on there.”

Following that same concept, heat, with the idea of temperature and phase changes, Jim asked students to think about temperature and boiling water in greater depth. “I told the kids, next week on Wednesday we’re gonna’ boil water. You’re gonna’ watch water boil.” This activity perplexed students when suggested during class. They commented that they had no idea why they would spend time watching water boil. That prompted a discussion of possible findings and explanations for those findings. The boiling water activity occurred the following week. Jim explained the importance of the boiling water activity with the comment: “I don’t need to do any more teaching of that once you’ve built your own graph of it [temperature of water during a phase change], you’ll know what’s going on.”

Many of Jim’s instructional choices revolved around sparking the student’s interest and allowing the student to make connections of the science explanations with real experiences. “I want to do something to set up an experience that gets them curious.” Jim used that curiosity and the questions that followed to reinforce new science concepts and connect those new ideas to knowledge constructed in previous units.

Science and engineering practices. Jim seemed to miss the “science” and “practice” parts of the phrase “science and engineering practices” when asked about it. His initial response was “the science and engineering standards — I have a hard time working that into every unit.” Jim went on to describe an engineering project from first semester.

> We built roller coasters out of pipe insulator and marbles and stuff like that and I gave them criteria and I made them make a sketch of what they are going to build and build it and figure out what didn't work and modify your sketch. So, I mean, the package had to be turned in. But to me, that was pure engineering.

Jim's example illustrated an engineering project that incorporated many of the science and engineering practices such as developing and using models, analyzing and interpreting data, and obtaining, evaluating, and communicating information (National Research Council, 2013a, p. xx).

Although Jim claimed to have minimal science and engineering practice built into his course, there were clear examples of those activities both in his roller coaster engineering project and during the classes I observed for this study. Developing and using models was a key component of Jim's retrieval activities — students had to explain the model of the atom through words and pictures; those models of an atom were subsequently used to explain the formation of compounds. Jim routinely expected his students to evaluate and communicate information. Students were required to present their information "retrievals" to the class; the class was encouraged to "edit/revise it/improve it". All of these activities were key components of science practice. Lab activities routinely required Jim's students to analyze and interpret data. Students were expected to construct and defend explanations based on data and observations. During the calcium chloride and sodium chloride lab activity Jim's students had to predict what was going to happen when they combined the chemical with ice water; after completing the procedure they had to compare their prediction with the results then explain the changes they observed. Again, these were all examples of the science and engineering practices described by the NGSS authors (National Research Council, 2013a).

Scientific argumentation. NGSS encourages scientific argumentation: defense of scientific claims based on evidence (Grooms et al., 2015). Jim acknowledged the importance of this skill:

> I think it's pretty important, especially right now as we're debating stuff like climate change and things like that. There are so many things now that come up where you can just be fed a line of bullshit. And without some background to be able to filter that out and come to your own decision you're just going to accept whatever opinion you get from whoever your news source of choice is.

Even while recognizing the importance of scientific argumentation, Jim expressed frustration with student demonstration of the skill.

> They don't have it. They don't, a lot of them don't wanta' argue or construct an argument. The way I'm trying to encourage that is to make them more comfortable just at defending their positions and their knowledge and stuff in class.

Despite this opinion, Jim regularly required students to question reasoning and evidence, evaluate explanations, and defend conclusions based on data and logic - skills that are part of scientific argumentation (Colson & Colson, 2016). Jim required students to defend their ideas presented in the form of a "retrieval". Students had to defend conclusions based on data and observations drawn from laboratory activities. This science practice is also a component of scientific argumentation. Although Jim could not identify scientific argumentation in students during his course, the students were demonstrating many of the skills that make up scientific argumentation during common class activities.

Other Teaching Practices

Phenomena. Jim utilized scientific phenomena to encourage curiosity and fascination in his students. He remarked, “Give them something, get them interested in it, let them start playing with that and that can drive them into wanting to know why it does what it does.” Jim used a single phenomenon to introduce the theme for the second semester of physical science: particles.

> So, for example, I want to do something to set up an experience that gets them curious. So here’s how the second semester started: I made the determination because it’s my chemistry half of the year, that my theme was going to be particles till I was done teaching the chemistry stuff. Particles is gonna be my theme, so I went and bought a $30 fog machine at Party City, filled the room full of fog, got out the lights and lasers from the light unit that isn't in the state standards but it came with our kits, cranked up the Pink Floyd over the PA in my room and had the kids come in and got them thinking about why does the fog move the way it does? Take your flashlight: what's going on with the dust particles here? Why does those things move the way they do? Well, they’re hitting something. What are they hitting? Well, it’s the air. What are they hitting in the air? Because I mean, prove it to me. And eventually the kids got there without me telling them — well they’re hitting the air molecules, molecules in the air. I said, but you can’t see them. Yeah, but you can see the other things moving. I said, “Bingo.” I said, “You’re exactly where Albert Einstein was about 120 years ago. Perfect, you should get a Nobel prize for this.”.… So, that's the type of things I try to set up in my class.

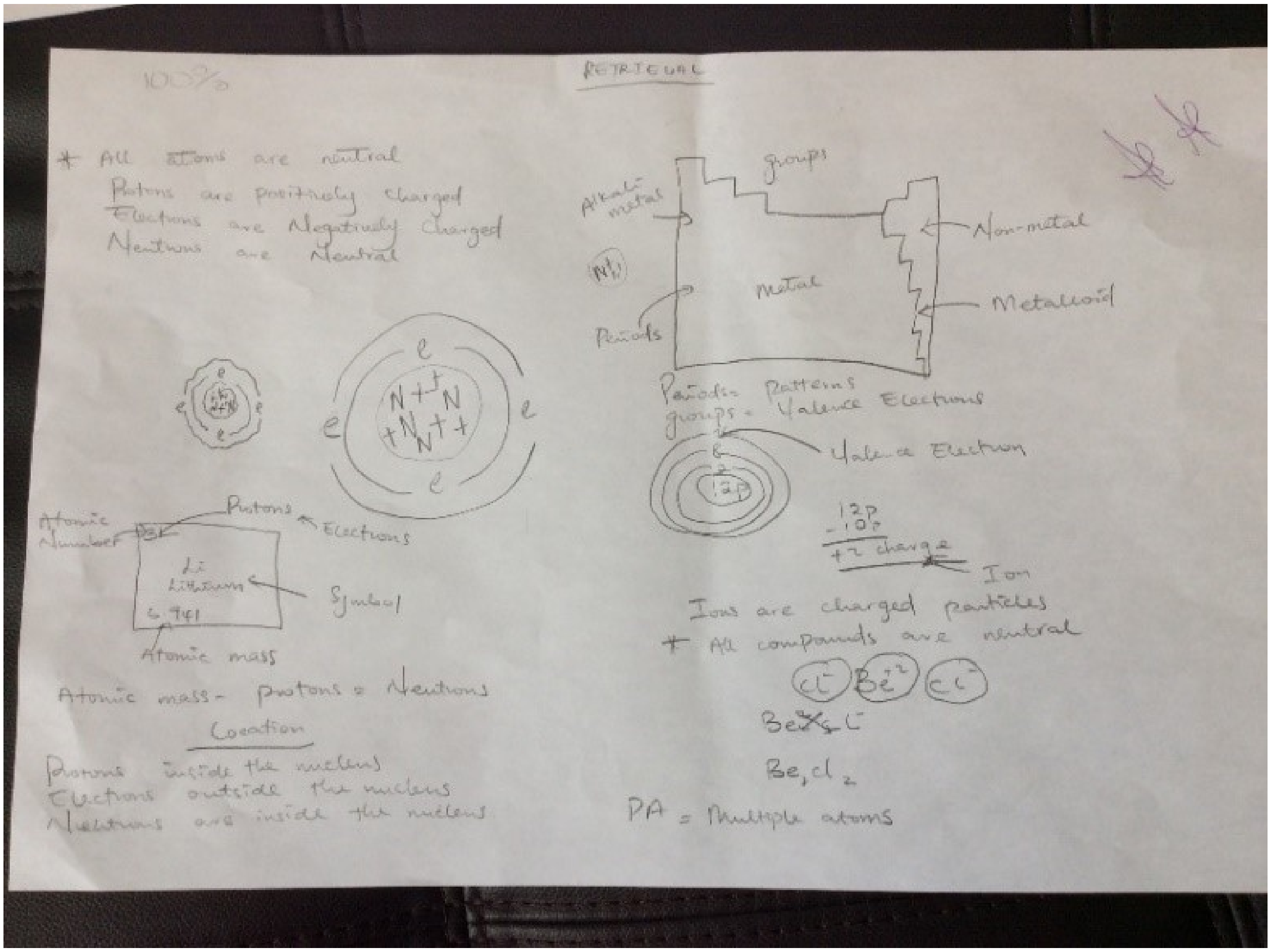
Jim returned to the fog and the particles in the fog regularly during the entire chemistry semester. The experience with the fog allowed the students to attach science language and concepts to a common event. Jim used the fog as "an experience that gets them curious" and referred to it regularly as students built knowledge about atoms, molecules, and chemical reactivity.

Jim's teaching practices. Jim, in all the efforts observed during this study, made efforts to link science content to student experiences and pre-existing knowledge. He incorporated inquiry into class discussions and laboratory activities. Jim's lessons featured science and engineering practices. One of the biggest challenges Jim identified was scientific argumentation: he found it difficult to successfully incorporate in classroom instruction. These NGSS components were not stand-alone lessons or activities. Inquiry, science and engineering practices, and scientific argumentation were incorporated into the teaching practices and activities Jim chose to use in classroom instruction.

When asked about teaching practices, Jim said, "My favorite teaching practice is probably retrieval. Teaching the stuff to kids in small chunks and having them, multiple times per class period, go and put it down on paper, edit/revise it/improve it." Based on ideas about learning and how the brain works from *make it stick* (Brown et al., 2014) and a graduate course he took last year, Jim taught his students how to organize ideas with two-dimensional representations he calls retrievals.

Jim's students were using new information immediately after it was introduced in class, as they incorporated that new information with existing knowledge in retrievals. "I'm teaching them a better way to learn, actually. Because that's how your brain learns. It [the brain] wants to know — this is important and I'm going to use it." Jim's retrieval teaching practice was not content specific. Retrieval encouraged students to connect content and ideas. Retrieval supported NGSS and science learning because students were asked to link new knowledge with pre-existing ideas and form their own understanding of concepts.

Jim utilized retrieval during class almost every day. He used it as a presentation strategy, a study mechanism, and as an assessment tool. Retrievals contained words, pictures, and/or equations; often all three were present. Figure 5 is an example of a student retrieval that includes words and pictures. Jim was able to quickly assess, based on this retrieval, the level of this student's understanding of the parts of an atom and some of the features of the periodic table.



RETRIEVAL

100%

* All atoms are neutral
Protons are positively charged
Elections are Negatively Charged
Neutrons are Neutral

Atomic mass - protons = Neutrons

Location

Protons inside the nucleus
Elections outside the nucleus
Neutrons are inside the nucleus

Periodic patterns
groups = Valence Elections

12p
-10e
+2 charge

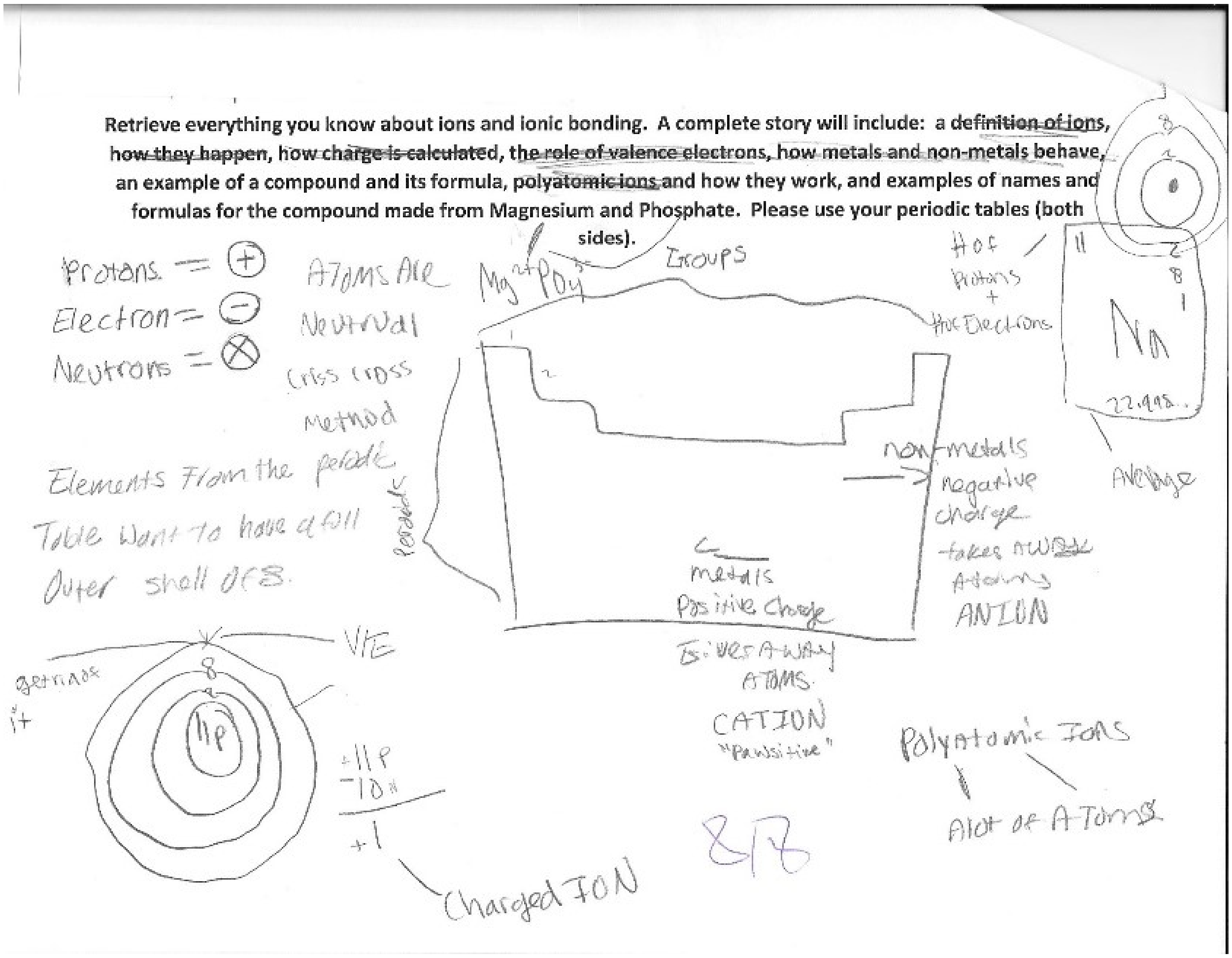
Ions are charged particles
* All compounds are neutral

Be Cl
$BeCl_2$

PA = Multiple atoms

Figure 7 Student retrieval using words and pictures

Retrieval allowed each student to represent the concepts in a manner that is logical to him or her. "They're all different. It's their story and when they own the story, they know it." Jim continued, "I give them feedback on it. You know, I asked you for examples here. I don't see any examples of what those things are. Um, I don't know you know it until you can give me an example." Jim required retrievals on each unit assessment, Figure 6. "I think that is a way better assessment of a kid's learning than a worksheet or a test or a quiz."



Retrieve everything you know about ions and ionic bonding. A complete story will include: a ~~definition of ions~~, ~~how they happen~~, ~~how charge is calculated~~, ~~the role of valence electrons~~, ~~how metals and non-metals behave~~, an example of a compound and its formula, ~~polyatomic ions~~ and how they work, and examples of names and formulas for the compound made from Magnesium and Phosphate. Please use your periodic tables (both sides).

Figure 8 Student retrieval on unit assessment

Jim regularly utilized hands-on activities in the classroom.

I think the hands-on stuff works for a lot of the kids, so I try to incorporate labs. I try to give less instruction with labs now than I used to in the past mainly because the more I tell them what to do the more it's my learning, not theirs.

Jim's students performed a simple lab activity – mixing chemicals with ice water – during one of the classes I observed. Those students were able to see for themselves the changes in temperature with the addition of different substances. Jim realized the critical nature of those experiences commenting, "I don't need to do any more teaching of that once you've [experienced it yourself], you'll know what's going on."

Jim's teaching practice shifted as he has gained more experience teaching. "Most of the videos I thought were so cool five or six years ago, I've realized are terrible." Jim had not "gotten the science books off the shelf in years", instead relying upon hands-on experiences and other methods of presenting information. He avoided Powerpoints and formal lectures in favor of his interactive class presentations and student retrievals.

Other Themes

Jim believed his role in the classroom was greater than science teacher. "I realize I have an opportunity teaching 120 kids who probably don't like science … to impact them and I actually have more important stuff that I can teach them than Newton's laws or the structure of the atom." Jim made a point to develop relationships with his students. He spent a few minutes at the beginning of each class talking about things that are important to the students via the "good stories". Jim chose to devote Fridays to social emotional "stuff". "I don't teach any science on Fridays, period." Instead of science he talked with the students about various topics. The topic one spring Friday was, "What do you want people to know you for?" Jim fostered relationships with his students and created a safe space for deeper conversations. Jim asked "kids to take a wider look and realize – you're part of a larger community. And you're important and you're valuable."

Jim understood his role as a science teacher. He chose to use his classroom for more than teaching science. His students expected these conversations. “They’re used to it with me. If I don’t do that on a Friday they wonder what’s up.” Jim could only guess at the effectiveness of the discussions, but he noted, “If it hits two or three kids it was a day well spent.”

Case 2: Andy

Andy had been teaching high school science and math classes for 15 years, all in the state of Kansas. Andy had a bachelor’s degree in physical science and a master’s degree in education. Andy came to teaching through an alternate pathway after many years in another career. Andy was teaching physics and physical science in a large suburban high school.

I observed Andy during two of his physics classes. Most of the physics students were juniors, a few were seniors. Students were distributed around the room, two to a table. Eighteen students were present during the first observation; 23 students were present during the second observation. Figure 7 is a sketch of the classroom during the first observation and Figure 8 is the classroom during the second observation; each x indicates a student sat at that space. Andy’s desk was at the front of the room with a dry erase board/projector screen on that wall.

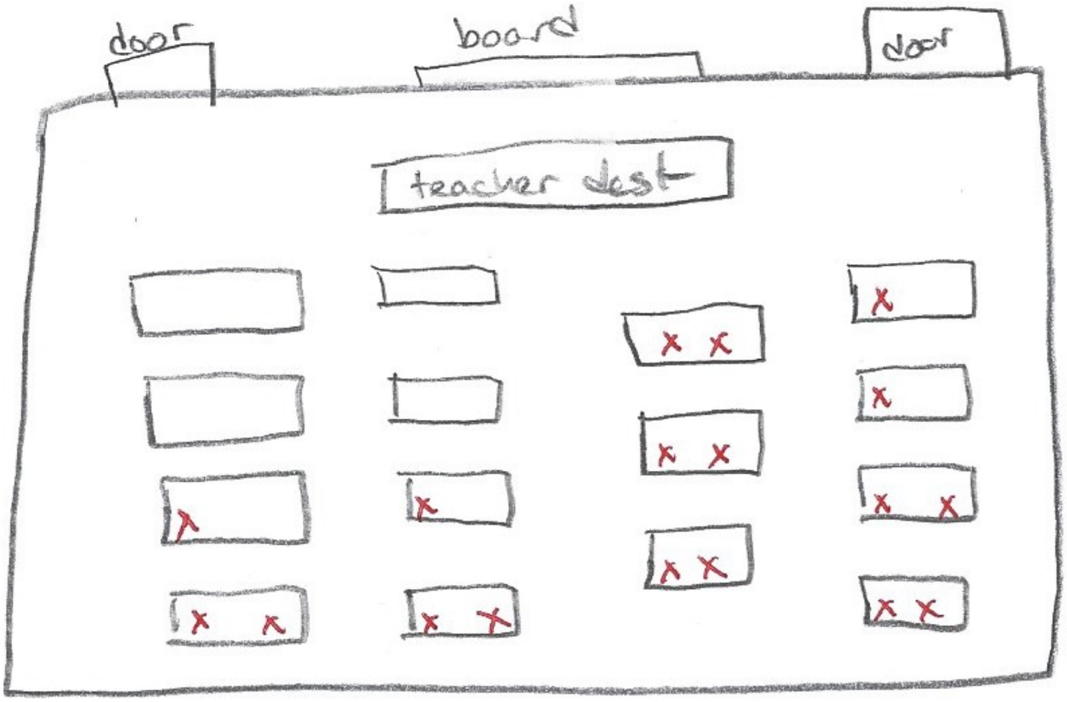


Figure 9 Andy's classroom – observation 1

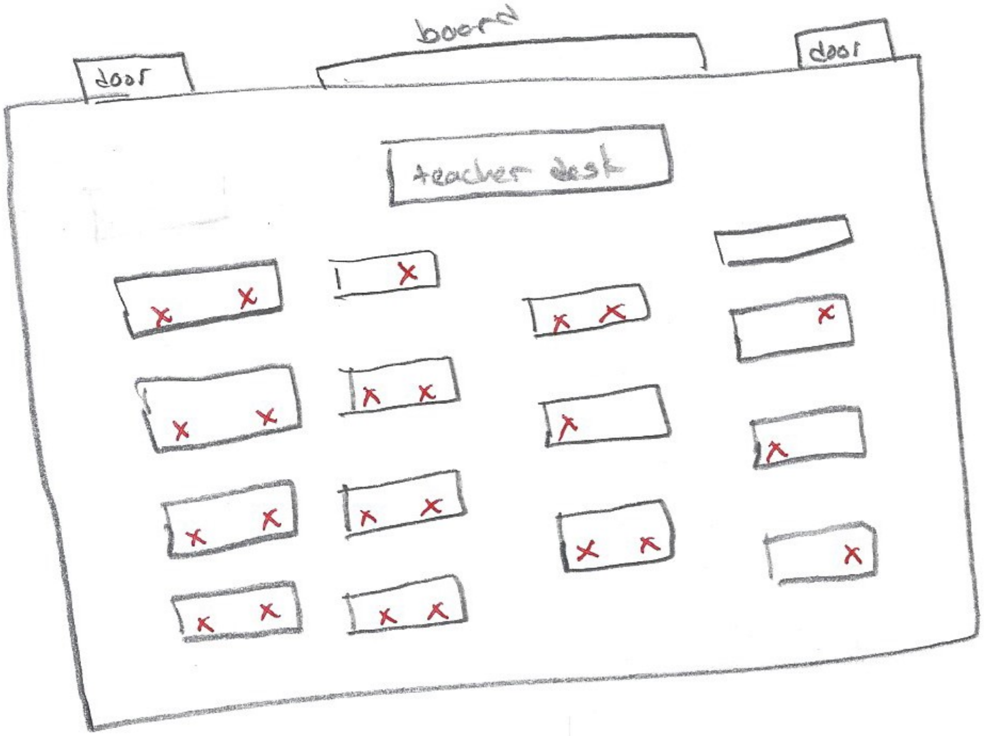


Figure 10 Andy's classroom – observation 2

Both days I observed Andy's class he greeted students by name as they entered the room. During my first observation of Andy's class the students did a lab procedure involving frequency, resonance, and pipe length. Before starting the lab, Andy reviewed a practice test the students had taken the day before. Andy noted the questions that most of the students missed, including a question on resonance and frequency that immediately led into the pre-lab questions students completed before class.

After reviewing the pre-lab questions, Andy quickly checked each student's answers and allowed them to take lab equipment and begin data collection. Some students went to the hallway to work on the floor; others used the tables in the classroom. Andy moved from the hallway, to the classroom, and back to the hallway as he asked students questions and provided guidance for appropriate lab technique. As groups finished the lab they returned the materials to the front desk of the classroom and turned in the completed lab assignment.

Another class of students was doing a different lab activity when I returned for the second observation. Again, during this class Andy greeted students as they entered the room and reminded several students that they were missing an assignment and asking when they were planning to come in to complete it. After the bell rang Andy began instruction. The first twenty minutes of class were used for a Powerpoint presentation on the electromagnetic spectrum. After he finished the content, Andy described the day's assignments: a lab activity and brief report. The lab activity required students to compare the spectrum of "white" light or sunlight to the spectrum of a fluorescent light source. For the report students had to find and summarize an article about one part of the electromagnetic spectrum. The students spent the remainder of the class collecting lab data and researching the electromagnetic spectrum.

NGSS Description

Andy described NGSS as “an attempt to teach less [content] in more depth” with a secondary goal “to try to link science to other things.” He continued,

> My impression was [that] they wanted to focus students on the key ideas that they would need to use throughout the rest of their lives. So they [NGSS authors] picked topics that would be most effective for that. And they wanted to do that as opposed to having a very broad brush covering everything. But I think they have accomplished the exact opposite of what they sought to accomplish.

Andy’s concerns with NGSS began during the development of the standards. Andy “wrote the district comment on NGSS, and it was kind of hard to figure out because it [the standards] was so disorganized.” He expressed two primary concerns to the NGSS authors:

> One was just — you’re adding more to what we’re doing, which is the opposite of what you’re saying, and then the second one … you just came to the conclusion that it takes the AP [Advanced Placement®] people two years to do physics and electromagnetism, why do you think that normal kids, even if it’s not as hard, will be able to do that in a year?

Andy’s frustrations with NGSS escalated when he saw only minimal changes after public comments were submitted to the NGSS authors.

> Well, what was the purpose of asking people if you aren’t gonna listen? And if you’re nominally doing that because you think it’s important then, either you’re not willing to listen or you don’t understand how to incorporate comments that are coming up.

Despite his dissatisfaction with the process of NGSS development and the final product, he made efforts to modify his physics course to accommodate the content changes required by NGSS.

Referring to the physics content, Andy found it “more difficult to cover subjects in depth ‘cause there’s more to cover.”

NGSS Professional Development

Andy was part of his district group that divided the NGSS between the high school courses. That was the extent of any PD he received on NGSS. “So we got no textbooks, we got no test support. We got no … activities or labs, or anything like that you could do.” He described the process of incorporating NGSS, we “fumble along and see what works.”

Nonformal professional development. Andy’s district regularly provides professional development for its teachers. Andy rarely finds those experiences beneficial. “The professional development we have, where everyone sits in there, are generic subjects that generally no one finds of much value as they’re too generic.” There are a few nonformal PD experiences that contributed to Andy’s teaching practice.

> Now, sometimes there is a professional development that has value. I’ll give an example. We used to have old clickers. I forget the two different versions of them, I’ve had both. But anyway, we were going to laptops …and the clickers wouldn’t work anymore. So most of the district professional development you have a choice of what class to go to. So I went to one where they had, it was on Socrative. So, they explained it enough so that I could take my quizzes, without having to re-write, you know, a thousand questions, and use them. But the number of times that there is something like that is, you know, really, really low. It’s usually completely absolutely worthless.

Andy empathized with the PD organizers: “I get that it is hard to centrally come up with professional development.” That did not override his attitude towards most of the building and district provided professional development opportunities.

Andy's department had regular weekly professional learning community (PLC) meetings. Andy and his colleagues hoped that PLC time would be an opportunity to collaborate with the other teachers in the subject areas. That rarely happened because each of the teachers had a different set of commitments during PLC time; the subject area teachers could only meet once every two or three weeks. "Every time I can meet with [the other physics teacher], I meet with [him]. And the physical science people, I can only meet one of them like every third week or something." Andy and his colleagues used the time available with the other subject area teachers to align unit and course assessments with the eventual goal to use that assessment alignment to drive a corresponding alignment of science content and teaching practice between the different teachers in the building.

Informal learning. Andy credited two mentors with greatly influencing his teaching style and practices. Andy was impressed by a math teacher he spent time with during the early days of his teaching career, "the other thing that he was very good at with the kids was he could explain something unbelievably clearly." Another teacher Andy observed during his teacher education, a physics teacher,

> had, I would call it, a hands-off class. That was, he would have a very simple lecture, and then the kids had to, generally, do word problems on their own. And they would come up and ask for help. And he, every once in a while, had labs and activities. But he had set something up where they had to learn on their own. And what I found was, in general, the less I talk, the more the kids learn. Because then they're doing.

Andy's teaching style and teaching practices were influenced by these mentors he encountered early in his teaching career. Andy continued to have close, informal collaboration with his teaching colleagues. Whenever he had a question about instruction or content or needed a new lab idea, Andy would go to the neighboring physics teacher, “the first thing I do is ask [him].”

Andy’s informal learning included independent study of NGSS both during the development of the standards by the national committee and again when his district was adapting the science curriculum to meet those standards. Both activities required Andy to read and review the standards with an awareness of the existing district science curriculum. These experiences contributed to Andy’s understanding of NGSS. Andy also used the internet as a source for classroom resources, “the next place I go is … to the web because I’ve already, to over-simplify, done every single lab and activity in all the books we’ve got.”

Transfer of NGSS Knowledge to Teaching Practice

Andy incorporated NGSS content into his physics course. He routinely utilized science and engineering practices and required student application of crosscutting concepts in class assignments and discussions. Andy made modifications to the content included in his physics course based on NGSS. Andy did not attribute any of his understanding of NGSS to PD; he credited his understanding of NGSS to the time he spent reading NGSS during the writing process and during the district’s distribution of standards to subject areas.

Science content. NGSS had a large impact on the content Andy taught in his physics course. “They took what we had before and added a fifth quarter.” Andy explained that

> the committees built the standards, and you ended up with something that — from my view and the view of the other physics guy we’ve got and the people who finally realized what happened when we had to implement them — all came to the conclusion that, we now have to teach a whole lot more. So instead of being narrowly focused, it now becomes even more dilute.

Andy offered the following explanation of the impact of NGSS implementation on physics content in his classroom.

> There are more topics to do. So the way we squeezed in NGSS was, in second semester, to oversimplify it, we took a third out of everything we did in individual units, and then squeezed NGSS stuff in. So things you did that would reinforce ideas so people would understand it better were now replaced by something that was kind of related to what the unit was, but not directly related.

Andy, working with the other physics teacher in his building, came to the current plan for the physics course based on decisions made at the school district.

Andy's district distributed the NGSS standards between the existing high school science courses. Two years earlier a group of science teachers representing physics, biology, and chemistry met and went through the NGSS. "The short version was, we were going to teach all of the standards. Anything that was a requirement somewhere in NGSS, you had to put it in there." Andy went on to explain that "biology got some [of the standards], chemistry got some, and physics got some."

After the district group determined what standards would be incorporated into physics Andy and his building colleague met to decide how to modify the science curriculum. For the physics course they

> looked at each unit and said, 'Okay, what can we get rid of even if we like doing it that you don't absolutely have to do to understand an idea even if it helps understanding a whole lot better?' So we listed, by unit, what we got rid of.

Andy described how they eliminated rotational force, equilibrium, and torque from the physics curriculum including instruction on the solar system and star systems. The original thermodynamics material was “stop[ped] at just mixing hot and something cold”; the heat of the Earth, weather and climate change were added to the unit.

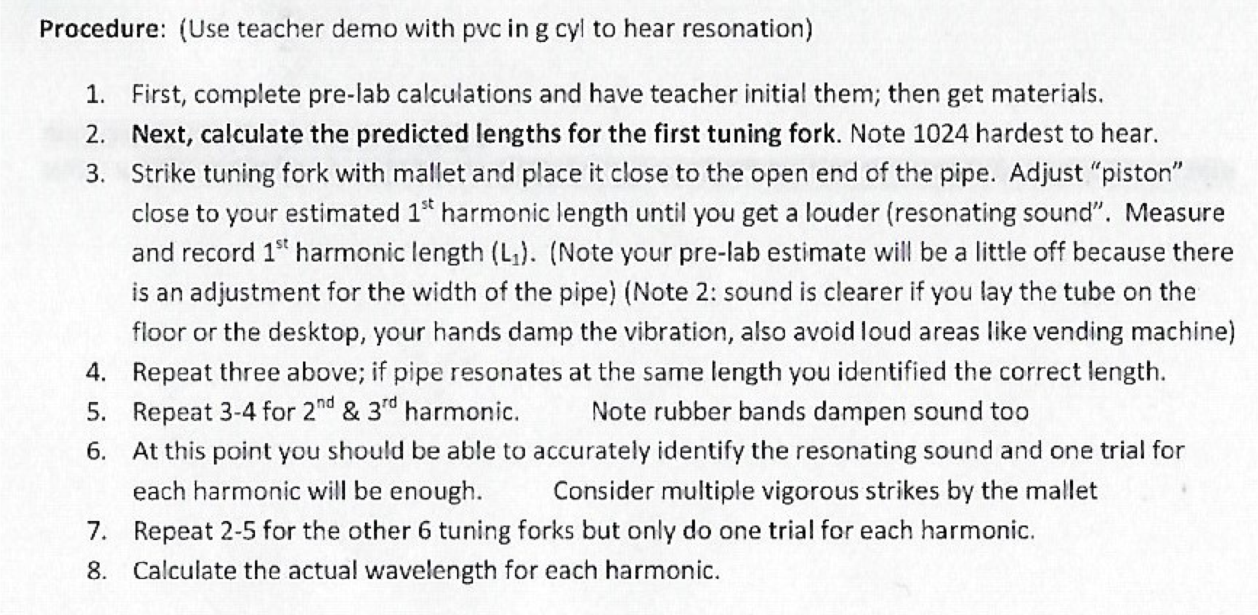
Andy questioned some of the choices made by the NGSS authors as it related to science content and the potential for student learning.

> They got rid of the basics up front. And if you don’t know the basics you can’t do the other stuff. And then they said, ‘Oh, that’s going to go away and we’re going to do all this cool stuff.’ Well, you can’t do the cool stuff if you don’t know the basics.

In another example, Andy noted, “So we’re doing this stuff that, if you knew what you were doing, explains why motors work. But we don’t have the time and there’s no requirement to explain motors.” Andy expressed concern that the changes to science content were detrimental to student depth of understanding of physics ideas and contain much that “you generally can’t practically use in every-day life. You would have to do a whole lot more.”

Crosscutting concepts. Andy’s class activities often incorporated crosscutting principles. During the frequency and pipe length lab students were expected to recognize patterns and scale and proportion. Cause and effect was an obvious component of the lab: students had to adjust the pipe length – the cause – and observe the change in the sounds – the effect. During the second observation – Andy’s electromagnetic spectrum lab activity and project – the students had to identify patterns of visible light and note the scale of the observed light. The day was spent studying different portions of the electromagnetic spectrum – a model frequently used in science.

Inquiry. Andy described inquiry with the statement, “You give people just enough guidance so they kind of try things out and then will learn on their own.” Andy’s students had to do inquiry on a limited basis during the frequency and pipe length lab. Students received a lab procedure – see Figure 9. Despite the instructions, many students placed the tuning fork in the wrong position; others did not realize they needed a meter stick to make measurements. Rather than warning students of these issues at the beginning of class Andy let them have the opportunity to try things out before offering clarifications. As Andy moved from one lab group to the next, he asked questions: "What's the loudest point?" and "How did you predict 512?" Eventually all the groups were able to interpret the procedure in the manner Andy intended.



Procedure: (Use teacher demo with pvc in g cyl to hear resonation)

1. First, complete pre-lab calculations and have teacher initial them; then get materials.
2. **Next, calculate the predicted lengths for the first tuning fork.** Note 1024 hardest to hear.
3. Strike tuning fork with mallet and place it close to the open end of the pipe. Adjust "piston" close to your estimated 1st harmonic length until you get a louder (resonating sound". Measure and record 1st harmonic length (L_1). (Note your pre-lab estimate will be a little off because there is an adjustment for the width of the pipe) (Note 2: sound is clearer if you lay the tube on the floor or the desktop, your hands damp the vibration, also avoid loud areas like vending machine)
4. Repeat three above; if pipe resonates at the same length you identified the correct length.
5. Repeat 3-4 for 2nd & 3rd harmonic. Note rubber bands dampen sound too
6. At this point you should be able to accurately identify the resonating sound and one trial for each harmonic will be enough. Consider multiple vigorous strikes by the mallet
7. Repeat 2-5 for the other 6 tuning forks but only do one trial for each harmonic.
8. Calculate the actual wavelength for each harmonic.

Figure 11 Frequency and pipe length lab procedure

Although Andy conveyed an understanding of the idea of inquiry, he expressed concerns about balancing inquiry with the quantity of physics content: "There's many things involved. There's usually some things they don't quite get the subtlety of and you don't have enough time to go over it." Andy made deliberate choices in laboratory activities that frequently did not include inquiry. Andy identified his priority, "The challenge in physics is relating the words to reality so the primary purpose of me for the labs is so they physically do something that is related to the concept." Andy had concerns about the results of student inquiry.

> … but it's so easy if they have misconceptions about something and then you let them go off on their own and they just reinforce their misconceptions. So I don't argue with the concept, I just don't see the means of doing it the way that they would like it done.

Andy recognized that sometimes student labs do not reach the desired conclusion. He described a lab that his physical science students did.

> They just couldn't get conservation of mass. There's this Alka-Seltzer lab you can do. So I tried it and - the way that they wrote it up — it really didn't work. … And the kids would say, 'Well, mass is not conserved.' And I would have to agree, yeah, mass was really not conserved.

Science and engineering practices. Andy, when asked about science and engineering practices, suggested that those ideas were not reflected in his course. "We don't really do that. AP 1 and AP 2 [Advanced Placement® Physics 1 and Advanced Placement® Physics 2] do a lot of that, but we don't really do that with engineering practices." Despite that claim, several examples of science and engineering practices were noted during Andy's classes. The frequency and pipe length lab required students to use mathematics and computational thinking: the calculations and associated pipe length and engage in argument from evidence: answers to Andy's questions during class and questions on the lab assignment. Science and engineering practices were also important components of the electromagnetic spectrum lab and project. Students had to ask questions and define problems: the research project; use models: compare the spectrum of the light to the visible spectrum; analyze data: the light spectrum activity; and obtain, evaluate, and communicate information: the research project.

Scientific argumentation. Andy does not believe that he requires his students to engage effectively in scientific argumentation. He suggested that his students were not able to defend conclusions based on evidence, at least

> not to the extent that it actually means something. They, I mean nominally, at the end of the lab they have to explain why they either got good or bad results or what the outcome was. But it's, it's generally a big enough of a hurdle just to understand what's happening in the lab.

Andy's assignments and questions in the classroom forced students to practice scientific argumentation. In both classes observed for this study students had to evaluate explanations and question reasoning and evidence. Some of this was built into the assignment; some of it occurred through the questions Andy asked during the class: "Why did you pick that length [referring to pipe length in the frequency lab]?" or "How did you predict 512?"

Other Teaching Practices

Andy does not believe his teaching practices were greatly affected by the implementation of NGSS. "I don't think that the [teaching] practices have changed, but it's more difficult to cover subjects in depth 'cause there's more to cover." Andy favored classroom activities that minimize lecture and presentation, preferring "something where they are doing it, as opposed to primarily me talking." He has transitioned, when possible, from classroom demonstrations to class labs or activities.

> I do a lot less demos than I used to. 'Cause I found demos help the smart kids. The other kids see it and then it's, it's lost. So I try to do less talking and have them do more doing. That's the general thrust of that. The demo's kind of an example of that.

During both of the classes I observed students spent the majority of the class time actively engaged in a hands-on lab activity rather than passively listening to a presentation.

Andy realized that he managed the new content differently. “With the new stuff we tried initially to do the least amount of educational effort and see how the kids reacted to that.” For Andy that typically meant a Powerpoint followed by an activity or a research paper on the topic. “If a Powerpoint with a simple assignment was not enough, then we would add something else to it. So, in electromagnetism, we have added a noticeable amount of labs that we hadn’t done before and largely weren’t being done [before NGSS].” These choices were made to incorporate the missing NGSS content with minimal time and effort. Andy noted, “In general, that has worked out.”

Other Themes

Andy’s attitude towards NGSS might be influenced by this impression:

> At least in our district, most of the schools aren’t teaching NGSS. They just blow it off and said, yeah, it’s a piece of paper. But nobody checks, nobody is competent to know what I’m doing in my room. So I can do whatever I want. I am, I’m over-stating it to a certain extent, but not completely.

Despite his opinion about district-oversight, Andy modified the content in his physics course to incorporate the additional NGSS material.

Andy’s attitude towards NGSS seemed negative. Andy contributed the district comments to the national NGSS committee during the development of the standards and received no acknowledgement of his concerns and saw no changes to the standards.

> What was the purpose of asking people if you aren’t gonna listen? And if you’re, if you’re nominally doing that because you think it’s important than, either you’re not

> willing to listen or you don't understand how to incorporate comments that are coming up.

Much of Andy's concerns were focused on the amount of physics content he was required to incorporate in his course. "We now have to teach a whole lot more. So instead of being narrowly focused, it now becomes even more dilute." Andy questioned some of the material included in the standards. "There is a lack of comprehension by the people who made the standards on the level of knowledge somebody has to have to be able to understand something useful out of that." Andy was dissatisfied with the inclusion of magnets and photoelectric effect.

> They had all those little micro-requirements where you got to, you know, come up with a device that uses the photoelectric effect. Uh, okay, nice to know, but not … practically useful. Because even if someone knows it uses the photoelectric effect who cares?

Andy thought many of the NGSS physics requirements were inappropriate for the high school curriculum and "had to be obvious to anyone who looked at it. And it was just, nothing was done."

Case 3: Jessy

Jessy had been teaching high school science for seven years. This was her first year teaching in Kansas. Jessy had two bachelor's degrees in science fields; she worked in research prior to beginning her teaching career. Jessy began teaching with a Temporary License and earned her professional license while teaching full-time. Since completing her professional teaching license Jessy added a master's degree in education to her resume. Jessy was teaching physical science and chemistry at the time of this study.

I observed Jessy's physical science classes; approximately a week later I returned and observed a different physical science class. In both classes students were working on parts of a major project: a case study called Yvette's Brave Battle (National Center for Case Study Teaching in Science, University at Buffalo, 2013). The students sat around a U-shaped group of tables. Figure 10 represents the classroom and student distribution of the classroom for both observations. Jessy moved around the inside and outside of the U-shape during the classes. The lab stations around the perimeter of the room were not used during the classes I observed.

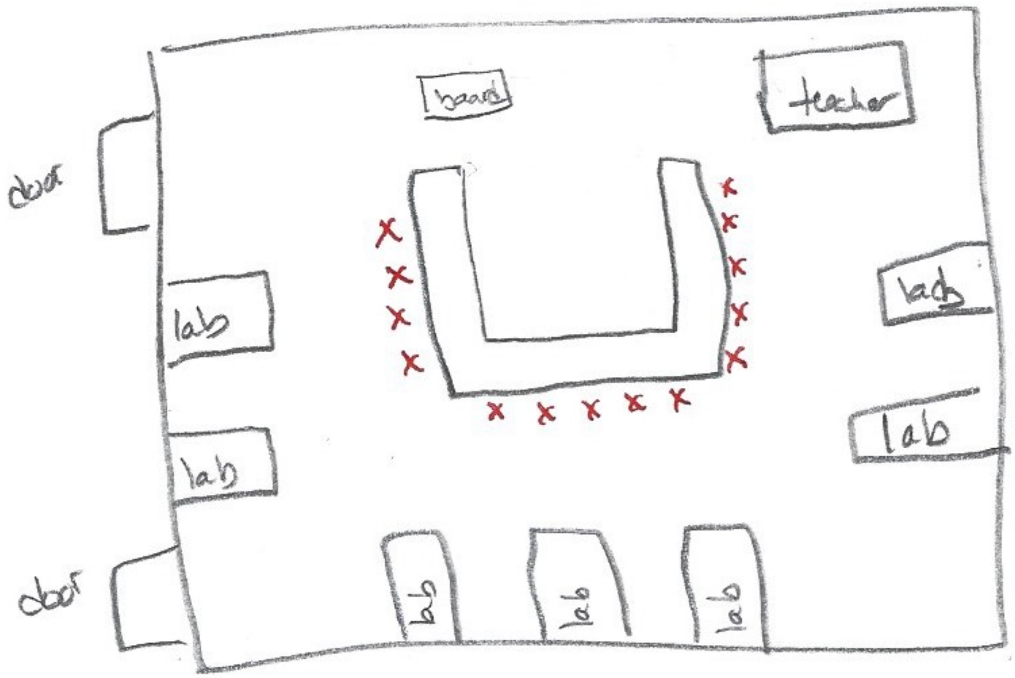


Figure 12 Jessy's classroom - observation 1 and observation 2

Each of Jessy's classes consisted of 14 students; a para-professional educator was also present during both classes. As each student entered the room Jessy greeted him or her by name. She congratulated students about recognitions from an awards program that occurred earlier in the day and asked another about a field trip. One student asked, "What are we doing today?" Jessy responded, "Science, same as every day." As the bell rang Jessy noted, "there it is …"

Several students provided the rest of the sentence, "… the sound of opportunity." Jessy asked students to put phones away and began instruction.

Jessy's classes had started working on the case study prior to these observations. Jessy's students were exploring chemical reactions through the case study: Yvette's Brave Battle (National Center for Case Study Teaching in Science, University at Buffalo, 2013). Students received a part of the case study with accompanying tasks: questions, summaries, and research. Jessy required students to draw story components in panels on a comic book, see Figure 11, to be used to help each student remember significant ideas from the case study. The class would work on each part of the case study for two or three days before getting the next installment of the story. The comic book was only one of the assignments associated with each part of the case study.

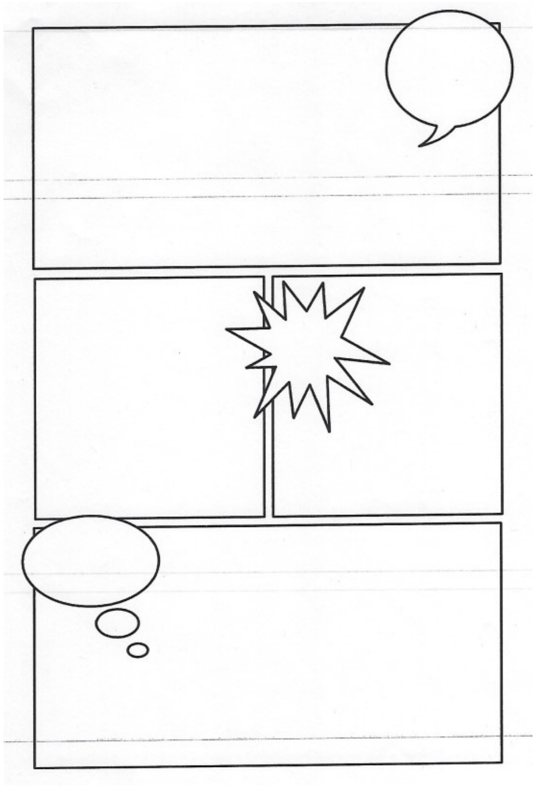


Figure 13 Blank case study comic book

The two classes I observed were very similar in format. Jessy began each class by asking students to take out the comic book and other assignments. Each day, before introducing a new section of the case study, Jessy led the students through a review of Yvette's story from the previous day. Students were encouraged to look at their comic book and the research questions if they did not remember parts of the story. Following the review, the class read the new part of the case study. Jessy interrupted the story regularly with questions for the students. When the group finished reading the new piece of the case study Jesse explained the day's assignment and research requirements. Students spent the remaining class time working on the questions and researching the chemical reactions represented in the case study. Jessy encouraged students and asked questions as needed.

NGSS Description

Jesse had an abrupt introduction to NGSS. "At my first district professional development meeting in August, when I got together with all the other science teachers, they kept using the acronym. And I had no idea what it stood for." Jesse explained her ignorance, "I just moved to Kansas [from a state that had not adopted NGSS] and my previous schools had not adopted them as science standards yet." Following that experience Jessy "did a little bit of research, … over time, I've done a lot more research." Jessy, combining her own research with explanations from colleagues, developed an understanding of the NGSS.

Jessy explained, "It [NGSS] has three things: not only your core [science content], but it's got cross-cutting concepts and the science and engineering practices that go with it." Jessy expanded on her explanation of NGSS.

> If we have to go broad and philosophical, it's to prepare students for the future. … And so the hope is to prepare students who have the skills to be able to not only use current

> technology – which they're doing pretty well on, but to create and implement science knowledge … in a helpful way for everyone. And so, NGSS seems to be having those cross-cutting concepts, specifically, and the science and engineering practices, seem to help students with problem-solving, but in the realm of science. How do we see a problem, solve a problem? And what does that look like? And so if we can get them more practice with that process, then later on they see a new problem that we may have never talked about in class, they might be equipped to have those steps to work towards solving it.

Despite her recent exposure to NGSS, Jessy confidently offered an explanation of the standards. She noted that NGSS "can be overwhelming to somebody when they're just introduced to it." But "the purpose of it [NGSS], I bought into it right away. Because it's what I do anyway. That's why I teach science." Although NGSS as a set of standards was novel for Jessy, the rationale and science skills integral to the standards corresponded to Jessy's understanding of science teaching.

NGSS Professional Development

Jessy was unfamiliar with NGSS at the beginning of the school year, having come to Kansas from a state that had not adopted NGSS. Jessy was new to NGSS, her school district was not. Jessy noted, "I'm getting, kind of, the tail end, I feel like, of the district's push on NGSS. So I had to really do my own research — what is that?" Jessy "spent this year kind of trying to figure out what I have taught in the past, what the district requires me teach, and how those Next Generation Science Standards align with all of that." Jessy has learned much about NGSS and science teaching: some of that from district-provided professional development, but most from her own self-directed learning.

Nonformal professional development. Jessy credited district provided professional development programs and department professional learning communities with providing contributions to her NGSS understanding and teaching practice. Jessy recalled two programs offered to the science department early in the school year.

> We started out as a large group, so it was all science disciplines, kind of all in the same room. But then we did break into our specific disciplines and I was with chemistry. And we did have an actual lab like you would carry out with your students. But we were the students and we had one of the district chemistry teachers who's very experienced and had been to NGSS training lead the lesson. And so, that was great. I mean, we did a hands-on chemistry lesson on electrical conductivity in solutions. And the lab itself was aligned to NGSS standards and how we do that, helping the student design their own work, and that kind of stuff.

The program facilitator, an experienced colleague, guided the group and gave suggestions "on how to teach it, not how to do the lab as a student." At least one other district-provided training Jessy attended "focused on phenomena-based learning [that] is aligned with NGSS."

Jessy found her science department professional learning community (PLC) to be very helpful as she's learned about NGSS. "That professional learning community is super-supportive. And so they share a lot of resources. And so I know where to go if I need it." Jessy's building had a goal of increasing project-based learning. The science PLC devoted time to project-based learning, discussing "what does that look like in your classroom, in your content?" This year Jessy's PLC explored curriculum resources for eventual adoption. Those conversations contributed to Jessy's NGSS learning.

> One of them that we're talking about, and no decisions have been made, is STEMscopes. It's a company that puts together teaching materials and learning materials for students and teachers. And they align all of their units to NGSS standards. And so, that helps me a lot actually, when I was kind of plugging through some of their resources that they gave us.

Jessy found the PLC discussions and material to be important to her learning. The time spent sharing ideas with one another was critical to Jessy. She noted, "I really do believe we're better together than we are on our own."

Informal learning. When asked about her learning experiences with NGSS, Jessy suggested that "the largest contributions has been by my own intrinsic motivation to find out." She did a lot of her own research and "a lot of self-inquiry and our district science director has helped me a little bit in understanding those things [NGSS]." Jessy's confidence with NGSS increased over this first year with the standards, but she continued to seek clarifications. "I … go to the NGSS homepage when I need something that's very explicit." She described those experiences, "I keep reading through and keep reading through and I keep reading the same material over and over again until it's in there [Jessy's brain] and I keep that in mind as I'm lesson planning."

Jessy respected the experiences of her science teacher colleagues, "they're a wealth of information." One nearby teacher, in particular, was an important resource for Jessy's first year with a new building, new students, and NGSS.

> She's a plethora of resources all wrapped up in one. And she knows a lot of online resources too, that you can get things from, that whole idea of not re-inventing the wheel.

> … She’s tried may different things and found that the ones that work really, really well for her students and so she’s confident in them and, it does help me if I need them.

Jessy did not hesitate to reach out to colleagues for ideas. Continuing that mentoring and colleague sharing pattern, other teachers in the building started to recognize Jessy’s experience and began reaching out to Jessy as a resource. “This semester I’ve had a few more [teachers] coming to me…. I think they’re recognizing some of my strengths.”

Transfer of NGSS Knowledge to Teaching Practice

Jessy made deliberate decisions to adjust her physical science content and incorporate NGSS-influenced activities in her lesson plans.

> I was able to cut content out and fill that with activities that were more aligned to NGSS like the projects and stuff where students have to communicate and develop models and plan and conduct experiments. … Before they were doing a little less of that and I was delivering more content.

Jessy incorporated more project-based learning in her classes.

> I think that was two-fold: it was a push from my school because we are currently trying to become more and more project-based so the students are more hands-on, less direct instruction in general. That wasn’t necessarily NGSS, but it works well with it because the NGSS standards, you can camp on those science and engineering practices for a long time when we’re applying it the concept in the classroom. And so, something as simple as, like an egg-drop project, which is like, classic. Everybody’s done one…. How do I take that to the next level? How do they use their …research and development, prototype, refine it, production, and that kind of stuff that, that engineering process — when it comes to something so basic?

Jessy made plans to continue modifying her course to increase the influence of NGSS-recommended practices. "I want some more inquiry up-front…. I would love to end my unit with [the students] being able to describe how people already solved this problem, and how the science they've learned could solve the problem."

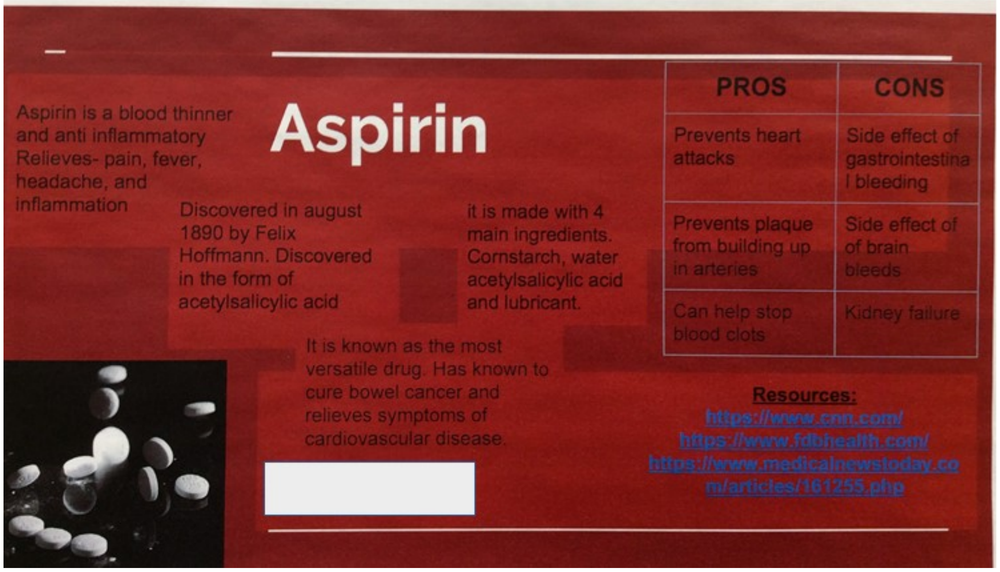
Science content. Jessy found that NGSS had an impact on the physical science content she brought to her classroom. Rather than a change in the content, Jessy considered NGSS

> more of a refinement. But NGSS requires, in physical science, much less content than my previous schools. And so, I was able to cut content out and fill that with activities that were more aligned to NGSS like the projects and stuff where students have to communicate and develop models and plan and conduct experiments and things like that. Where before they were doing a little less of that and I was delivering more content.

Jessy utilized the opportunities presented by a decrease in the quantity of science content in her physical science course to emphasize the fundamentals of science and the relationships with life.

> I think, in high school, especially in this physical science class you've been able to observe, we're looking at the basics. You know, introduce them to the things they've already seen but from the perspective of science. And then, what can we use that for? What do people use that for and how is it applicable to their everyday lives and to their future? I think that's kind of my goal when I look at things.

That applicability and relationship to students' experiences is evidenced by the class projects displayed in Figure 12 and Figure 13 and the cancer case study project — both link physical science content to practical life experiences.



Aspirin

Aspirin is a blood thinner and anti inflammatory Relieves- pain, fever, headache, and inflammation

Discovered in august 1890 by Felix Hoffmann. Discovered in the form of acetylsalicylic acid

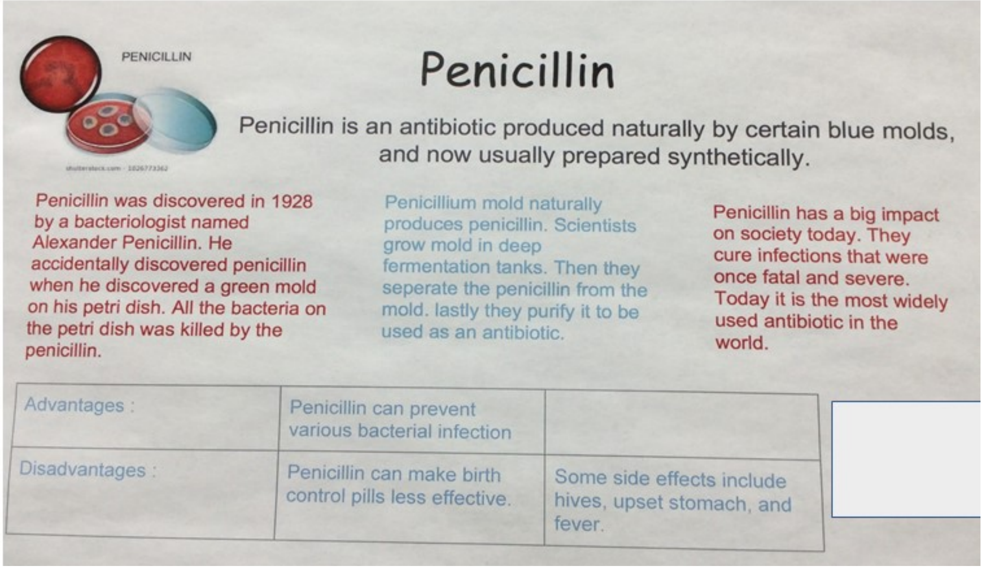
it is made with 4 main ingredients. Cornstarch, water acetylsalicylic acid and lubricant.

It is known as the most versatile drug. Has known to cure bowel cancer and relieves symptoms of cardiovascular disease.

PROS	CONS
Prevents heart attacks	Side effect of gastrointestinal bleeding
Prevents plaque from building up in arteries	Side effect of of brain bleeds
Can help stop blood clots	Kidney failure

Resources:
https://www.cnn.com/
https://www.fdbhealth.com/
https://www.medicalnewstoday.com/articles/161255.php

Figure 14 Student research project displayed in Jessy's classroom



Penicillin

Penicillin is an antibiotic produced naturally by certain blue molds, and now usually prepared synthetically.

Penicillin was discovered in 1928 by a bacteriologist named Alexander Penicillin. He accidentally discovered penicillin when he discovered a green mold on his petri dish. All the bacteria on the petri dish was killed by the penicillin.

Penicillium mold naturally produces penicillin. Scientists grow mold in deep fermentation tanks. Then they seperate the penicillin from the mold. lastly they purify it to be used as an antibiotic.

Penicillin has a big impact on society today. They cure infections that were once fatal and severe. Today it is the most widely used antibiotic in the world.

Advantages :	Penicillin can prevent various bacterial infection	
Disadvantages :	Penicillin can make birth control pills less effective.	Some side effects include hives, upset stomach, and fever.

Figure 15 Student research project displayed in Jessy's classroom

Jessy utilized NGSS emphasized content and practices and incorporated a school-recommended project-based learning approach to increase student learning during a physics unit.

> So when we did a unit on forces and motion and that type of stuff we did an entire project where they had to design a device for a specific purpose, you know, to meet a problem.

> And it required the students to think more, on top of me teaching them things they never knew. It allowed them to discover a lot more than, than for me to do direct instruction.

Jessy explained that the design and build project allowed her students to understand the science content of forces and motion in a much different way than if the students had simply done routine worksheets and textbook work.

Crosscutting concepts. The case study project that was utilized during the classroom observations for this study presented several examples of students working with the crosscutting principles of NGSS. With Jessy's encouragement, students were able to connect cause and effect between Yvette's test results and her diagnosis. The structure and function of elements and compound patterns were important in both the diagnosis and treatment of Yvette's cancer. Students used patterns of symptoms to track Yvette's cancer to the original source of disease. Frequently students made these connections independently; when necessary, Jessy offered a critical idea or question to lead a student to the expected idea.

Inquiry. Jessy considered inquiry an integral part of teaching science. "I think students need to be able to make choices, decide on procedures, and then carry them out and see if it worked." She commented on the link between inquiry and student learning:

> They have to draw conclusions from something they created. And that does require them to think deeper. And it also develops student interest. And so, when they're coming up with something and then carrying it out, they're much more interested in it, and I think their brains are just willing to go deeper at that point than if I had just said: follow these instructions, do this lab.

Jessy made efforts to incorporate inquiry and student choice into classroom activities.

During the classroom observations Jessy's students suggested questions for Yvette, the patient in the case study. This forced the students to consider the situation and evaluate what information would be necessary to identify the source of Yvette's symptoms and plan treatment. Jessy provided another example of an inquiry-based learning experience.

> We just did a lab last week in our chemical reactions unit where the students were kind of discovering the law of conservation of mass…. We called it a throw-back lab. So they were using just simple ingredients, vinegar and baking soda. And they knew what was going to happen and that was the goal. I didn't want them to do an inquiry lab with really caustic chemicals. They had just a set of supplies that I left out on the instruction desk. And I said, use these supplies and demonstrate the law of conservation of mass. And then I gave them like, 20-30 minutes to just stare at the supplies and think. And they collaborated with each other and they had to come up with a procedure of an experiment that I didn't give them. They had to come up with one that would actually demonstrate the law of conservation of mass. And then once their procedure was something that could do that I would sign off on it and then they'd carry it out. And they had to, at the end, construct an explanation that said, yes, my, my experiment demonstrated the law of conservation of mass because … And they had to analyze their data and report it and communicate it in written form. So that process took a lot more time than if I had just said – here, we're gonna mix these two, capture the products, then determine the mass before and after and compare them. I didn't tell them that. And so, while the lab itself was kind of juvenile, the process of getting there and carrying it out was on them, rather than on me.

Jessy and her students found value in the simple experiment that provided opportunities for students to construct their own procedure, decide what data needed to be collected, and reach conclusions following that procedure.

Experiments, especially those designed by students, did not always produce the expected results. Jessy considered that an important part of the process. "Learning through failure, I think, is a huge part of inquiry-based learning." When students had unexpected findings Jessy expected them to "go back and explain why it didn't [work]." She worked with the students "to get to that point, where they can verbally or in written work, describe why it failed." Jessy noted that students often learned more from failed experiments because they were forced to analyze the process and consider how their actions influenced the results.

Science and engineering practices. Jessy identified several science and engineering practices in the lesson plans she prepared for the case study lessons observed during this study: obtaining, evaluating, and communicating information; constructing explanations, and using computational thinking. During the class observations students were seen asking questions and defining problems related to the case study and designing solutions based upon evidence presented in the case study and information gathered through research.

Jessy described some of the progress she noted with student practice of the science and engineering practice: planning and carrying out investigations.

> They will collect information verbally and auditorily and even just using their eyesight, looking around the room, so they're, by the end of the year they've trained to be much, much more observant…. And so, sometimes they'll tweak their experiment in the middle, because they can see another group has figured out something that's much better.

Jessy emphasized the value of multiple experiences with experimentation and science processes to student growth and understanding of the scientific practices. Those experiences did more than teach skills, they also led to student development of knowledge.

Hands-on experience like laboratory experiments served an important role in Jessy's classroom. The case study unit provided another opportunity to explore science in an authentic medical context. In each of those types of lessons Jessy incorporated the science and engineering practice of obtaining, evaluating and communicating information. Student projects displayed around Jessy's classroom presented more examples of gathering and communicating information, see figures 12 and 13. For this project pairs of students were required to research a chemical or a science career and present the important ideas about that topic in an organized mini-poster.

Scientific argumentation. Jessy described scientific argumentation as "being able to support your work with facts". She noted that "I don't know that I've been able to get, especially physical science students, to that point." Jessy's students were expected to engage in scientific argumentation. During the case study project the students evaluated explanations from classmates and the case study material, questioned reasoning, and made claims based on evidence – all skills associated with scientific argumentation.

Other Teaching Practices

Phenomena. Jessy used the phenomenon of cancer to engage her students in the case study project. "It's super-relatable. It strikes a chord with people, in general, including students." Jessy used natural phenomena to offer the opportunity to initiate conversation or introduce a science concept. "I love to put a problem in front of students and just say why? Or how?" Sometimes the phenomenon introduced a question and fostered deeper learning and exploration. Jessy commented,

> If I can get students to relate on a personal level to the content, then I can drag them deeper into the chemistry of it. Maybe the part they didn't care as much about but I've hooked them with something that does mean something.

Jessy's teaching practices. Jessy realized the importance of student engagement and used that idea to guide her lesson planning and teaching practice selection.

> And so, sometimes it helps to go with something I'm more passionate about, and not just selfishly, but because the best teaching comes from teachers who believe in what they're teaching. And so, sometimes I do spend just a little bit more time on something that strikes a chord with me. And, over time, I see students buying into it a little bit more. So getting that buy-in from the students themselves, I mean they're our greatest stake holders in this whole education process, so, that helps.

Jessy's choice of the cancer case study project was deliberate: it was relevant to many students' lived experiences, related to the course chemistry content, and allowed the students to explore the content in different manners. Jessy's teaching practices during the case study encouraged students to make choices and link the idea with existing knowledge, allowing each student to build science knowledge individually.

Jessy's lessons and class activities combined cross-cutting concepts and science and engineering practices. She noted that

> NGSS seems to be having those cross-cutting concepts, specifically, and the science and engineering practices, seem to help students with problem-solving, but in the realm of science…. And so, if we can get them more practice with that process, then later on they

> see a new problem that we have never talked about in class, they might be equipped to have those steps to work towards solving it.

Jessy's classes incorporated the ideas to build student knowledge and science skills that may not be realized in the current physical science course but will hopefully contribute to future success with science and engineering applications.

Jessy included regular opportunities for her students to experience hands-on learning. "I have been challenged by this current school to use more project-based learning which aligns with NGSS really well. Especially with the science, the engineering piece of it." She described a student-designed conservation of mass experiment and a force and motion engineering project students had completed earlier in the course. "I've done a couple more lengthy project-based learning units … so the students are more hands-on, less direct instruction."

Jessy frequently incorporated critical thinking and class discussions to encourage student learning.

> I favor meaningful discussions. I love it when students have the opportunity to challenge each other and what they're thinking, so they can actually process the science in their own brains and not just me giving them information and requiring them to memorize it. I want them to have opinions and to voice those opinions and then also to constructively feed off the opinions of their peers.

Jessy, with the cancer case study, encouraged students to think critically.

> This particular case study that you're seeing today, it's the phenomenon of cancer. Like, what is it? How do we use it? And, particularly in physical science, we're looking at chemical, and chemical reactions…. And so, how are chemical reactions used or a part

> of, even, the cause of cancer? Or the diagnosis of cancer? Or even the treatment of cancer?

Jessy filled her class lesson plans with opportunities for student discussion and engagement.

Other Themes

Jessy, in addition to teaching science, expressed a desire to help her physical science students gain some basic "student skills": "keeping track of papers, coming to work, or coming to school on a regular basis." She explained that the sophomores enrolled in her class were there because "physical science gives them one more year to mature as a student and in their basic science understanding to prepare them for chemistry [the following year]." Jessy devoted time each day to developing positive rapport with her students: greeting students, asking about their day, offering positive comments about small successes.

Jessy's goals for her students go beyond science instruction.

> I think, if I can get students from where they're at, and increase their ability to think, and to draw conclusions, to process the how and the why of the things that they see around them, and then use that in a positive way – then I've met my goal. This is very broad, but I want them to be able to practice their critical thinking skills, their problem-solving skills, their positive discussion skills, their collaborative skills, group, you know, working in groups. Those types of things, sometimes supersede the, the small little facts that we're trying to teach them.

Jessy did expect her students to leave physical science understanding gravity, fire, and other simple chemistry concepts. Her hope was that, as the students left her class at the end of the school year, that each would have greater science knowledge and improved student skills.

Cross-Case Comparisons

The purpose of this qualitative multi-case study was to explore the experiences of veteran high school science teachers as they learn about NGSS and transfer NGSS knowledge to teaching practice. The conceptual frameworks of NGSS; learning delivery mode: formal, nonformal, informal; and transfer of learning were used during data analysis and the following cross-case comparison.

How Do Veteran High School Teachers Describe NGSS?

The Next Generation Science Standards recommend a comprehensive science curriculum that includes science and engineering practices, crosscutting principles, and scientific argumentation. That framework is accompanied by modifications in science content and inquiry-based learning experiences.

All three teachers believed that NGSS was an attempt to reduce the amount of science content so teachers and students could focus on real-world applicable material and science practices that would prepare students for the future; one of the three teachers considered those efforts a failure as the amount of required science content increased for the physics course. Two of the three teachers believed that NGSS is "the right way to teach science"; science instruction should use problem-solving and real-world examples to engage student interest, practice science skills, and improve student learning.

The NGSS incorporated specific language to describe science content, teaching recommendations, and student objectives: disciplinary core ideas, crosscutting principles, science and engineering practices, inquiry, phenomena, and scientific argumentation. During their second interview, each teacher was asked two questions related to NGSS: describe the overall goal of the Next Generation Science Standards and how would you describe NGSS to someone who had never heard of it? When those responses were combined, the ten most common words related to NGSS that were used included the following: think, science, problem(s), help(ful), solve(ing), students, teach, know, accomplish, and applicable. Figure 14 represents the top 500 words used during the teachers' comments on NGSS. Other notable commonly used words were engineering, technology, practice(s) and learning. The teachers' language included several NGSS-emphasized terms; others were not often used in the responses to the questions about NGSS and the goals of the standards: crosscutting concepts, content, scientific argumentation, inquiry, and phenomena.

Figure 16 Words used most frequently in teachers' description of NGSS

The teachers in this study considered NGSS to be an attempt to streamline content and expand opportunities for problem solving and science practices. Their descriptions of NGSS included many key terms – solve, students, teach, engineering, practice, learning – but omitted other terms frequently associated with NGSS – crosscutting concepts, scientific argumentation, and inquiry.

How Do Veteran High School Science Teachers Describe Their NGSS-Focused Experiences According to the Classifications of Formal, Nonformal, and Informal Learning?

Only one of the three teachers associated a formal learning experience with current NGSS teaching practice. That formal learning experience, while impactful for this teacher, was not directly related to NGSS, but provided the teacher and his students a significant strategy for utilizing and organizing existing and new knowledge in a personalized representation. That strategy was instrumental in classroom instruction, student learning, and assessment.

When considering the frequency and value of nonformal learning experiences, the three teachers had different experiences. All three teachers participated in regular professional learning community (PLC) meetings; two of the teachers reported frustrations with scheduling collaboration with other teachers in their subject area. The third teacher found her PLC experience beneficial — the group regularly shared teaching practice ideas and resources. Each of the teachers had district or building-provided professional development (PD) opportunities. One teacher said that none of the PD programs offered by the school system featured NGSS information. Another teacher reported several years of science department PD devoted to NGSS, although he found nothing in those PD programs that he could easily adapt for use in the classroom. The third teacher recalled two NGSS-influenced PD programs: one on phenomena-based instruction, the other on inquiry in the laboratory. Both programs provided information and ideas that she was able to immediately incorporate in lesson plans and teaching strategies that she utilized in her classroom.

All three teachers described the importance of informal learning, especially the value of collaboration with peers or mentors. Each teacher identified a trusted colleague that provided ideas and feedback on NGSS and other classroom concerns. All three teachers reported regularly exchanging activity ideas and teaching strategies with other teachers. Two of the three teachers utilized self-directed learning, mostly through internet research, to analyze the NGSS and determine the influence on their science content and classroom practice. Both of these teachers relied upon the NGSS website (Next Generation Science Standards, 2015) for information and clarification of the ideas and content included in the standards.

Professional development played an important role for all of this study's teachers. Each teacher participated in nonformal learning programs; the influence of those programs varied depending upon the teacher's context and needs. All of the teachers indicated the importance of informal learning via collaboration and independent study to their understanding of NGSS and teaching practice.

How Do Veteran High School Science Teachers Transfer Knowledge and Modify Teaching Practices and Science Content as They Incorporate NGSS Specified Inquiry, Science and Engineering Practices, and Scientific Argumentation?

Each of the three teachers exhibited transfer of NGSS knowledge to the classroom. All three teachers made modifications to the science content in their courses – two of the three have eliminated some topics and gained time for other class activities and projects, the other teacher had to eliminate some traditional material to make room for new science content. All three teachers described modifications to their teaching practices designed to improve student learning, although only one of the teachers attributed that change to recommendations from NGSS. That teacher described the inclusion of Powerpoints, additional laboratory activities, and projects targeting content not included in the original course curriculum.

The NGSS describes crosscutting concepts of patterns; cause and effect; scale, proportion, and quantity; systems and system models; energy and matter in systems, structure and function, and stability and change of systems. These crosscutting concepts support student learning, provide "an organizational structure to understand the world" and should "connect [science instruction] … across disciplines and grade bands" (National Research Council, 2013a, p. xx). All three teachers incorporated the crosscutting concepts in class activities and instruction; all three encouraged students to recognize patterns and cause and effect, mostly in laboratory experiences. Two of the teachers emphasized patterns of chemical or physical behavior during classroom discussions. One of the teachers, during two separate lab activities, addressed the crosscutting concepts of scale and proportion and system models through hands-on learning experiences. Two teachers encouraged identification of structure of function of elements and compounds during class discussions and group reviews. The remaining two crosscutting concepts, energy and matter in systems and stability and change in systems, were addressed by one teacher during this study. Those ideas were part of a teacher-led introduction to heat and subsequent lab activity.

Two of the three teachers included regular opportunities for inquiry-based learning. The third teacher expressed concerns about inaccurate results and students attempting to link bad information to known science. Two of the teachers described a similar conservation of mass inquiry activity — one teacher's students saw lab results consistent with the scientific law and the other teacher's students' unsuccessful experiment that seemed to prove conservation of mass false. This unsuccessful inquiry experiment contributed to the third teacher's unease about inquiry-based learning.

The NGSS developers included a list of eight science and engineering practices (SEP) that "mirror the practices of professional scientists and engineers" (National Research Council, 2013a, p. xx); the SEP should be used in the K-12 science classroom to strengthen skills and support student understanding of science. Those science and engineering practices described in the NGSS are:

1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6: Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information (National Research Council, 2013a, p. xx)

All three teachers used a variety of the SEP in classroom activities during this study, although two teachers, when asked about the science and engineering practices, claimed that they did not do much of those in their classrooms. Each of the teachers offered opportunities for the students to ask questions and define problems: two during lab experiences, and the other during a class discussion about a medical diagnosis. All three teachers incorporated learning opportunities that required students to obtain, evaluate, and communicate information. Two of the teachers asked students to conduct research online and present their findings in written responses. The students in the third teacher's classes were encouraged to organize chemistry concepts in a visual display that was presented to classmates and discussed by the class. Two teachers encouraged student understanding of models in classroom discussion and lab activities. Investigations and experiments are a common activity in the science classroom. Two teachers offered students the opportunity to plan and carry out an investigation: one in a lab setting, the other with online research. Data were analyzed and interpreted by students in two teachers' classes. In each case the teacher offered guidance if the students struggled with finding the preferred connections. One teacher, through a lab activity and research project, encouraged the students to complete mathematical calculations and engage in argument from evidence. One SEP, constructing explanations and designing solutions, was not noted during this study.

All three teachers considered scientific argumentation a weakness for their students. Two teachers suggested students could not construct arguments defending or explaining science concepts until they understood the ideas. The other teacher suggested that the students were unwilling, rather than unable, to take a position on a science question and defend that position. Despite considering scientific argumentation a weakness for their students and their classroom practice, all three teachers required their students to explain experimental observations and provide evidence to justify answers — both are components of scientific argumentation.

NGSS instruction includes crosscutting concepts, inquiry, and science and engineering practices. Many of the crosscutting concepts and science and engineering practices described in NGSS were observed during this study. Each of the teachers regularly incorporated the crosscutting concepts and engineering practices in classroom instruction. Two teachers included inquiry-based learning activities for their students. Each teacher considered scientific argumentation a weakness for the students, but each teacher did encourage students to make efforts to construct explanations based on observations.

Other Teaching Practices

Other teaching practices were important to these three teachers. All relied upon hands-on activities, usually laboratory experiments. Two teachers described the use of phenomena as an important teaching strategy. Both suggested that introduction of a common phenomenon encouraged student interest and engagement; student curiosity often fostered exploration of concepts in greater depth. One teacher employed retrieval as a teaching strategy. This visual representation technique allowed the teacher and his students to connect new science ideas and content to pre-existing knowledge in a manner that was logical to the individual. The students combined new science ideas with known information to create greater science knowledge. Another of the teachers routinely incorporated meaningful discussions that required students to demonstrate critical thinking. This teacher employed engaging and real-life issues to encourage students to consider how science combined with actions and choices to affect the environment and society. Two teachers described classroom strategies that they no longer used regularly. One teacher commented that he shifted, whenever possible, to student experiments instead of classroom demonstrations to support student learning. Another noted that he no longer relied on textbooks and videos as classroom instruction tools.

Each science teacher had a preferred set of teaching practices. All relied on hands-on experiences to represent science concepts for their students. Depending on the teacher, other favored teaching practices included retrieval and meaningful discussions. Two teachers described their use of phenomena to provide a central focus or question that established a foundation for a unit of instruction. Each teacher deliberately selected teaching practices and classroom activities to support and enhance student learning.

Other Themes

Other themes emerged during the analysis of the interviews, observations, and documents. Two teachers emphasized goals for their students that did not focus on science learning. Acknowledging that his students were greater than a science course, one teacher devoted a day each week to “social emotional stuff.” During that class the teacher would foster student conversations about goals, their actions and repercussions, and their role in the community. Another teacher realized her students lacked basic student skills — organization, collaboration, working in a group, critical-thinking and problem-solving — and modified part of her course to encourage growth in those areas. She provided organization tools and offered regular opportunities for class discussion and collaboration. Both teachers considered the personal growth of each student at least as important as the growth in science knowledge and adapted classroom activities to support that.

One teacher suggested that there was little administrative oversight of NGSS implementation, primarily because “nobody is competent to know what I’m doing in my room.” This same teacher, while adapting his classroom curriculum to NGSS, expressed frustration with the NGSS development process and the resulting amount of content required in some science courses.

These science teachers, in addition to their efforts to teach the NGSS content and science and engineering practices, expressed concerns about their teaching, students, and classrooms. Two teachers, responding to their students’ non-academic needs, modified their course structure. One teacher questioned the ability of administrators who have not been educated about NGSS to reliably evaluate teacher performance.

Chapter Summary

Three teachers participated in interviews, allowed classroom observations, and provided documents for this multi-case study. That data are represented in three individual cases that were analyzed with a conceptual framework of NGSS, learning delivery mode, and transfer of learning. Following the individual case representations, the three cases were compared with one another. Teachers understood that implementation of NGSS would require a modification, often a reduction, in science content for a science course so more time could be spent on problem-solving and science practices. Professional development and learning, through nonformal and informal learning experience, was important to the teachers' understanding and implementation of NGSS. Teachers were able to incorporate the crosscutting concepts, inquiry, and science and engineering practices in classroom instruction; all considered quality scientific argumentation a challenge for their teaching. Each teacher had preferred teaching practices, but all included hands-on learning and other strategies that encouraged students to develop science ideas.

Chapter 5: Summary and Discussion

Chapter Introduction

This chapter includes a summary of the current study, a discussion of the findings, implications for practice, recommendations for further research, and a conclusion. This study explored the formal, nonformal and informal ways that veteran high school science teachers described their learning about the Next Generation Science Standards (NGSS) and how those teachers transferred NGSS knowledge and the NGSS goals of inquiry, science and engineering practices (SEP), and scientific argumentation to the classroom.

Study Summary

With the adoption of NGSS by Kansas and 19 other states (NGSS adoption map, 2014) and the associated shift for many teachers from traditional didactic teaching methods to NGSS recommended teaching practices, professional development (PD) became an important element for all involved with science education: state officials, district and building administrators, and classroom science teachers (National Research Council, 2013a, 2015; Pruitt, 2014; Wilson, 2013). For most teachers, PD was a combination of formal, nonformal, and informal learning experiences. Value of formal, nonformal, and informal learning experiences was only realized if teachers transferred learning or knowledge to classroom practice. Dufrene et al. (2005) described the transfer of learning as "a complex process leading to the high selective activation and application of knowledge in response to context" (pp. 155-156). The individual teacher determined the relevance of every learning experience and decided what ideas and practice to transfer to the classroom (Enderle et al., 2014; Hewson, 2007).

This qualitative multi-case study explored the NGSS learning experiences and transfer of NGSS knowledge to teaching practice by three veteran high school science teachers. A convenience sampling technique (deMarrais & Lapan, 2004) was used to identify the three participants that corresponded to the study criteria. Participants took part in two semi-structured interviews and two classroom observations and provided documents related to PD and classroom instruction.

Discussion of Findings

Many factors influence the teaching practices and classroom instruction observed in a science classroom. As noted by Harris et al. (2017): "The success of NGSS in K-12 education reform mostly depends on the teachers' ability to translate the standards into practical lesson plans and classroom activities coupled with the development of sound pedagogical skills" (p. 56). With the adoption of NGSS, practicing veteran science teachers combined existing knowledge and teaching pedagogy with new information as they learned about NGSS content and recommended science instruction practices. Each teacher used information gathered through professional development, formal and nonformal experiences, and informal learning experiences in conjunction with his or her pre-existing set of knowledge in a unique manner (Bowman, Jr. & Govett, 2015; Herrington & Daubenmire, 2016). This study explored the NGSS learning and implementation experiences of three veteran high school science teachers.

Description of NGSS by Veteran High School Science Teachers

When asked to describe NGSS, the science teachers in this study recognized and explained that NGSS was an intent to reduce the quantity of science content and include more opportunities to learn through science and engineering practices (Bowman, Jr. & Govett, 2015; National Research Council, 2012, 2013a, 2013b). As described by Krajcik et al. (2014) and

Duncan and Cavera (2015), these teachers understood that the NGSS were designed deliberately to support development of student problem-solving skills and introduce science concepts that would be important for the future of all students. Science content, rather than a collection of facts, was composed of real-world phenomena to be explored with science skills.

NGSS incorporates specific language: dividing science content into disciplinary core ideas with crosscutting concepts (CC) and science and engineering practices (SEP) (National Research Council, 2013a). Student learning goals are labeled "performance expectations" and incorporate science skills that include SEP, inquiry, and scientific argumentation. Duncan and Cavera (2015) explained: "the use of the word *practices* is meant to signal a shift in how we view inquiry-based teaching and learning" (p. 52); the CC are "thinking tools students can use when trying to understand phenomena in the world around us" (p. 54). Duncan and Cavera (2015) and Melville et al. (2015) suggest that the NGSS authors made deliberate choices in languge for the CC and SEP. "The meaning of the [science and engineering] practices is not just a side note" (Melville, Dowdle, & Campbell, 2015, p. 8). The terminology matters to a teacher's understanding of NGSS and its implementation in the classroom.

The teachers in this study, when directly asked to describe NGSS, used some of those terms: science, engineering, practice. Other terms had strong links to science education: problem, solve, students, teach, learning, technology. Most of the NGSS-specific terminology for the CC and SEP were absent from the teachers' description of NGSS. Two of the teachers, when asked to describe the SEP, referred to engineering projects, rather than the eight common SEP described by NGSS. This lack of attention to terminology could be significant to classroom teaching. If teachers do not use the language of crosscutting concepts and science and engineering practices to describe NGSS instruction, do they understand the interrelated nature of the ideas? Is there other language those teachers use to describe activities and teaching practices that NGSS considers crosscutting concepts and science and engineering practices? In a 2014 study of one district's adoption and implementation of NGSS, Lazzaro noted that those individuals who had a greater understanding of NGSS, including the terminology of CC and SEP, were stronger advocates for the standards. Nadelson et al. (2015) found that K-12 science teachers, even when they were confident with NGSS terminology, struggled with translating the CC and SEP to classroom practice. Friedrichsen and Barnett (2018) saw similar results: high school biology teachers familiar with the NGSS terminology had a difficult time implementing the standards in a manner that incorporated CC, SEP with the content. This group of teachers considered the SEP a separate requirement from the science content and overlooked the CC and engineering aspects of NGSS (Friedrichsen & Barnett, 2018).

The teachers in this study, like the teachers represented in the works of Lazzaro (2015), Nadelson et al. (2015), and Friedrichsen and Barnett (2018), had varying levels of understanding of NGSS, including the terminology. That level of confidence with NGSS terminology and understanding of NGSS structure is important to NGSS implementation and subsequent classsroom instruction. As noted by Melville et al. (2015), "teachers must be proactive in both discussing the meanings they attach to the documents and implementing those meanings in the classroom" (p. 7). The teachers in this study struggled with NGSS language and two claimed they did not use many of the SEP in the classroom. Despite that claim, many of the SEP and other NGSS recommended strategies, including inquiry and scientific argumentation, were observed during this study. There was discontinuity between the language the teachers used and the skills and practices observed in the classroom. A greater awareness of NGSS terminology and how it translates to the classroom, as recommended by Melville et al. (2015) would help teachers recognize the connections between science teaching practices, classroom activities, and student learning.

Description of NGSS-Focused Learning Experiences of Veteran High School Science Teachers

As veteran science teachers adapted classroom content and instruction to accommodate NGSS they relied upon professional development (PD) to provide venues to explore curriculum requirements and teaching practices (Lawless & Pellegrino, 2007). Formal learning opportunities did not play a role in NGSS knowledge for any of the teachers in this study. Only one of the three identified any formal learning experience, a summer college course, that contributed to teaching practice. That course, while important to the teacher's subsequent teaching practice, was not specifically about science teaching and learning, but was about the brain and how people learn.

Nonformal learning experiences, most often in the form of district- or school-provided workshops or science department professional learning communities (PLC), played a role in NGSS learning and knowledge for each teacher but was different depending on the teacher's circumstances and context. Department PLCs served as a community of practice (Hamos, et al., 2009; Lave & Wenger, 1991) for each teacher, providing opportunities to interact with a group of individuals with a common practice. Two of the teachers noted that their community of practice was only beneficial if they shared features beyond a common practice; those teachers only realized a benefit if the practice characteristics extended to a common subject and student population.

Two teachers found that time spent in nonformal learning experiences was not relevant to classroom instruction or covered an idea he already incorporated in teaching practice. Several factors may explain these perceptions. Each of these teachers had been active in the high school classroom for 15 years following another career. After that amount of time it could be argued that, as suggested by Kennedy (2016), these teachers “have already developed their practice” (p. 3) and would be abandoning a previous approach to instruction if they chose to incorporate new ideas. The teachers could be resistant to the mandated, top-down driven PD (Roseler & Dentzau, 2013) and/or, as suggested by Allen and Penuel (2015), unable to incorporate the new ideas because of a perceived lack of coherence between the PD and the overall instructional goals.

Another related factor to this resistance could be the veteran teachers’ expectation that NGSS will not be the last update to the state science standards; any efforts made to adapt curriculum and implement standards would have to be repeated in the relatively near future. The education system, including science education, is continually reviewing student learning objectives and societal expectations. Science education has gone through major shifts beginning in the 1960s with the inclusion of inquiry learning followed by substantial updates in 1993 (*Benchmarks for Science Literacy*), 1996 (*National Science Education Standards*), 2012 (*A Framework for K-12 Science Education*), and the most recent 2013 (*Next Generation Science Standards, For States, By States*) (American Association for the Advancement of Science, 1993; National Research Council, 1996, 2012, 2013a) . Mixed in between the science education updates are other major educational updates such as the No Child Left Behind Act of 2001 (No Child Left Behind Act of 2001, 2008) and the Common Core Standards Initiative (Common Core State Standards Initiative, 2017). With each iteration of substantial changes to education requirements practicing teachers are expected to process and understand the necessary changes to the curriculum, classroom instruction, and student assessments. Veteran science teachers, with a personal history that includes multiple modifications to science standards, may be reticent to implement NGSS because of an expectation that the next update to science education is only a year or two away. The challenge is to convince the reluctant experienced science teachers that NGSS will be the science standards for the foreseeable future and that those standards are beneficial to student learning.

In contrast, one of the teachers found nonformal learning experiences informative and immediately applicable to teaching practice. This teacher's circumstances were markedly different from the other two teachers in this study. This teacher was an experienced teacher but new to the school district and NGSS. Despite, or maybe because of the novelty, the teacher described the on-going efforts to understand NGSS and its impact on instructional choices positively, "it's what I do anyway." Van Duzor (2011) suggested that teachers would be more likely to learn, and transfer that learning to practice, if they felt a greater need for the material. Barnes et al. (2006) realized a similar relationship between learning and transfer to practice if teachers felt they could be successful with new skills. This teacher was an eager learner and new to the school and NGSS; NGSS was coherent (Allen & Penuel, 2015) with pre-existing ideas; that awareness may have contributed to the value this teacher placed on nonformal PD. This teacher, based on interview comments and classroom observations, found the nonformal PD offered by the school to be consistent with her understanding of NGSS and constructive to the development of NGSS knowledge and expansion of teaching practices.

Informal learning was an important part of NGSS learning and implementation. All three teachers described sustained relationships with one or more mentors and used these individuals, as described by Anagnou and Fragoulis (2014) as a source of support for instructional ideas and professional advice. Each teacher relied upon colleagues for more casual collaboration, especially for new teaching ideas or reinforcement of previously identified strategies. Baker-

Doyle and Yoon (2011) described the importance of this social support as teachers evaluate classroom and PD information and determine what they will incorporate in classroom practice. The teachers in this study, like the participants in Hardré et al. (2017), appreciated the opportunities to meet with other teachers in their subject area to exchange ideas. Both of these identified relationships — the mentor and the more casual collaborations — could be considered examples of social learning (Bandura, 1977, 1986). Both occur in social settings and the teacher is finding value in skills or information the mentor or collaborator has to share.

Internet research and study, as identified by Lohman (2000), was an important informal learning component for two of the teachers in this study. Each of those teachers utilized the NGSS website to clarify information about the standards, performance expectations, CC, and SEP. Much of the learning described by one teacher involved reflection (Schön, 1987) and internet research. "I go straight to [the] NGSS website and I keep reading through and keep reading through and I keep reading the same material over and over again." For this teacher the internet research combined with her classroom experience and deliberate analysis of a situation was key to her subsequent teaching choices.

The informal learning experiences of the teachers in this study were crucial to each teacher's immediate needs. Informal learning is chosen or driven by the learner (Garet et al., 2001), reflects the goals of the learner (Lustick, 2011), and is available when the learner finds it necessary (Jones & Dexter, 2014). The teachers in this study were able to find the resources to fulfill their NGSS learning needs through a variety of means.

Professional learning — learning that is related to the teaching profession — for all teachers, including those in this study, will be unique to the individual. Each teacher will combine any new ideas with his or her existing understanding of science content, science instruction, and teaching practice in a unique way (Bowman, Jr. & Govett, 2015; Herrington & Daubenmire, 2016). The three participants in this study had different PD experiences that were combined with different pre-existing understandings of science content and teaching practice. Despite those differences, all found value in professional learning, particularly the learning represented by informal experiences of mentorship, collaboration, and self-directed study through internet research.

The Transfer of NGSS Knowledge to Teaching Practice

NGSS, because of the limitations to science content in the standards (Bowman, Jr. & Govett, 2015), encourages teachers and districts to streamline the content in courses in order to emphasize fundamental skills used by scientists: inquiry, science and engineering practices, and scientific argumentation (National Research Council, 2013a). This impact of modification of science content varied, depending upon the course. The physical science teachers were able to eliminate some science content in their courses, making time for expanded class activities and projects. The physics teacher also eliminated some traditional physics content because it was not covered in NGSS but added some earth and space science material that was not covered before. The teacher explained: “They [the NGSS authors] took what we had before and added a fifth quarter.”

The physics teacher expressed frustration with the removal of physics content from the required material. He questioned the ability to teach some of the additional material without other necessary scaffolding concepts. Like Slater and Slater (2015), the teacher considered some of the removed material critical to science instruction. “Science content related to core physical laws has been removed entirely” (Slater & Slater , 2015, p. 61). Equally concerning was the addition of earth and space science material to the physics course. For this teacher the additional instructional time was a problem, as was a personal level of confidence in the subject matter. Teachers "lack the confidence and subject matter knowledge to teach effectively using inquiry-based approaches are less likely to recognize misconceptions and oversimplification of ESS [earth and space science] content" (Lewis & Lu, 2017, p. 304). The removal of content and incorporation of new material may cause struggles with NGSS implementation and instruction, as it did for this teacher.

The high school science teachers in this study regularly incorporated the crosscutting concepts (CC) and science and engineering practices (SEP) in classroom instruction and teaching practices. The teachers, as recommended by Reiser (2013), "support[ed] the knowledge building aspects of practices, not just the procedural skills in doing experiments" (p. 11). Students were asked questions that required them to explain decisions and evaluate information, "Why did you pick [that length]?" and "Why did it take so long to diagnose?" These higher order questions, as recommended by Krajcik et al. (2014), encouraged students to use logic and evidence to link their observations to overarching ideas and patterns. This type of curriculum – one that invites students to engage in scientific practices including "posing questions, developing hypotheses, designing and conducting experiments, examining and interpreting data, constructing arguments … and debating conclusions" (Kuhn, Arvidsson, Lesperance, & Corprew, 2017, p. 233) have been shown to improve student learning, particularly in the areas of investigation design, analysis, and argumentation skills.

The use of inquiry learning experiences varied with the study participants. Two teachers allowed their students to learn through inquiry and incorporated inquiry learning experiences regularly. Both commented on the importance of students initiating and designing investigations. One teacher noted, "They have to draw conclusions from something they created. And that does require them to think deeper. And … it also develops student interest." Those points of view align with the National Research Council's (2000) thoughts on inquiry: learners are engaged, priority is given to evidence, learners use evidence to justify explanations, and learners communicate their explanations.

The third teacher expressed concerns about inquiry as a pathway to student learning. He noted, "It's so easy if they have misconceptions about something and then you let them go off on their own and they just reinforce their misconceptions." Although this teacher understood the idea of inquiry and how to use inquiry in the classroom, he made a deliberate decision to minimize inquiry learning opportunities. Enderle et al. (2014), Hewson (2007), and Lustick (2011) explained the autonomy of the classroom teacher: he or she determines what has value and if those skills or teaching practices will benefit student learning. Inquiry, as described by the National Research Council (2000) and perceived by one teacher, was problematic and had the potential to confuse students. The teacher was concerned that students did not have the necessary skill set and knowledge base to differentiate between a poor experiment and commonly accepted science concepts. This teacher did allow students to experience inquiry learning in small ways – deciding how to do a vaguely described lab procedure or determining what data to collect; he was not willing to allow students more autonomy in laboratory activities out of concern that student results and subsequent explanations might not match the expected results.

The teachers in this study struggled with scientific argumentation in the science classroom. Each teacher identified scientific argumentation as a weakness for their teaching practice; however, each teacher required students to practice scientific argumentation skills as part of class activities: making or defending claims based on evidence in a lab assignment, comparing arguments in a research project, and questioning reasoning in a case study. One of the teachers described the use of "meaningful discussions" in the science classroom. That description included an awareness that students "actually process the science in their own brains"; expectations that students "voice those opinions and … constructively feed off the opinions of their peers"; and encourages students to "practice with discourse" — all ideas consistent with scientific argumentation. Grooms et al. (2015) explained the importance of scientific argumentation.

> In many ways scientific argumentation is the process by which *science*, as a discipline, develops and refines knowledge. When scientists put forth arguments in support of new ideas, the claims, supporting evidence, and rationales or justifications of evidence, are critiqued and evaluated by other scientists. (Grooms et al., 2015, p. 45)

None of the teachers in this study felt that their students were able to construct evidence-based arguments defending or explaining a science concept. Reiser (2013) suggested that teachers shift instructional practice from textbooks and teacher presentations to class discussions involving argumentation and consensus building about scientific ideas. Sampson, Enderle, and Grooms (2013) recommended that teachers highlight how students know information as they support claims and think and learn like scientists. Students should be encouraged to use classroom data to explain and support scientific concepts and generalizations. Classroom teachers should model how students can transition from laboratory observations to generalizations. The "claim, evidence, reasoning" framework (McNeill & Krajcik, 2011) can provide a structure for student representation of findings supported by data or other information. The teachers in this study, although they did not identify their efforts as components of scientific argumentation, incorporated scientific argumentation skills regularly in classroom instruction; one teacher even included “meaningful discussions” as a regular part of classroom instruction.

Each of these teachers transferred NGSS knowledge to their classroom: modifying course content and incorporated NGSS practices. Multiple NGSS crosscutting concepts and science and engineering practices were observed in each teacher’s classroom activities. Each of the teachers included scientific argumentation skills in student discussions and assignments. Two teachers offered students inquiry learning opportunities and encouraged their students to learn through that process. Despite an understanding of inquiry, the other teacher avoided that teaching practice. There was no transfer of knowledge or inquiry learning to practice for this teacher because he was not convinced his students would benefit from inquiry learning experiences. That teacher made a deliberate choice to resist transfer of learning to classroom practice.

Other Teaching Practices

The teachers utilized a variety of practices in their science classroom; all designed to support student learning. All of the teachers in this studied relied on “hands-on” learning, usually in the form of experiments, as an important component of science education. The teachers, based on their descriptions of hands-on learning, referred to active learning experiences like laboratory activities and experiments. Hands-on learning is often beneficial to student learning, but Furtak and Penuel (2019) cautioned about using deliberate language. If NGSS is learning science through common SEP, that language should be used. Hands-on could be simple manipulatives; the science experiments these teachers described involved NGSS CC and SEP, something much more involved and challenging than “hands-on” might imply.

Two teachers emphasized the value of phenomena to student engagement. One teacher explained, “I want to do something to set up an experience that gets them curious.” Beyond providing a curiosity, a phenomenon should provoke questions and possible explanations. As described by Reiser (2013) and the National Research Council (2015), the teachers used a phenomenon to introduce a topic or unit, then regularly re-visited that phenomenon throughout the unit to refine student understanding of the event with a goal of student development of explanations for the original phenomenon. One of the teachers in this study used a simple phenomenon, fog, as a theme for an entire semester of science instruction. He set up a demonstration the first day of the semester and returned to the phenomenon regularly during the remainder of the course.

One teacher relied upon retrieval as a teaching practice, learning activity, and assessment tool. As NGSS encourages students to build science knowledge in a way logical to the individual, this retrieval technique allowed students to make connections between concepts and represent knowledge in ways determined by each student.

Another teacher included opportunities for meaningful classroom discussions to foster development of student knowledge. Although this teacher considered “meaningful discussions” a distinct classroom practice, the description had similarities to components of scientific argumentation. The teacher described meaningful discussion this way:

> I love it when students have the opportunity to challenge each other and what they’re thinking, so that they can actually process the science in their own brains and not just me giving them information and requiring them to memorize it. I want them to have opinions and to voice those opinions and then also to constructively feed off the opinions of their peers. I think it’s very helpful for them and it’s going to be more meaningful for them. It also gives them practice with discourse.

Grooms et al. (2015) described scientific argumentation as “the cyclical process of critique, refinement, and evaluation [that] … leads to scientific arguments that are robust and supported by sound evidence and reasoning” (p. 45). A comparison of the two descriptions suggests that both contain ideas, an explanation of those ideas, justification of those ideas, and, potentially, adjustment of those ideas. As noted earlier in the chapter, the “meaningful discussions” described by this teacher could also be viewed as classroom examples of scientific argumentation.

Each teacher made deliberate choices in teaching practices based on personal preferences, previous experiences and a perception that a selected teaching strategy would support student learning. Those choices resulted in a variety of preferred teaching practices from each teacher that augmented the NGSS recommended strategies: “hands-on learning activities”, structuring a lesson or unit around a phenomenon, retrievals, “meaningful discussions”. Each strategy identified by the teachers came from one of several sources: common science learning activities presented in textbooks, NGSS recommended teaching practices, or learning experiences that were important to how that teacher learned science.

Other Themes

This study explored veteran science teachers’ understanding and implementation of NGSS in the science classroom. The data, particularly the semi-structured interview transcripts, highlighted ideas that were not specifically addressed in the study’s research questions but merited acknowledgement. Teachers expressed concerns that superseded NGSS and science instruction: student social emotional welfare and student academic skills.

The state of Kansas, in addition to focusing on academic learning, adopted Social, Emotional, and Character Development Standards for the K-12 education system (Kansas State

Department of Education, 2019). One teacher considered student social emotional welfare so important that he consciously nurtured student relationships each day and devoted Fridays to foster conversations about student roles and responsibilities in the community. This teacher wanted to demonstrate to his students that he cared and to present opportunities for conversations about character and choices; each of these goals is mirrored by an idea presented in the "Principles of Character Education" (Kansas State Department of Education, 2016). This teacher and researchers (Edgar, 2014; Li & Lerner, 2013; Yang & Bear, 2018) realized that time spent developing positive relationships with students had the potential for a positive impact on student learning, student engagement, and character development.

Early in the school year another teacher involved with this study realized many of the physical science students lacked basic academic skills. This teacher adjusted course expectations to include activities designed to assist students with homework and study skills and modeled many of those skills in the classroom. Gettinger and Seibert (2002) described the importance of study skills to academic success, particularly procedural skills and study skills. This teacher, realizing that students would benefit not just in science class, but in every academic setting, exposed her students to a variety of study strategies and guided them through the usage of those skills for the remainder of the school year.

Another theme emerged during this study – accountability for NGSS implementation. The NGSS authors and others (Harris et al., 2017; Pruitt, 2014; National Research Council, 2015) advocated for sustained NGSS professional development for all involved with science education to include district and building administrators. One teacher in this study suggested that administrative education had not occurred, noting, "Nobody is competent to know what I'm doing in my room." If NGSS is a shift in science education that is comprehensive and demanding for science teachers (Banilower et al., 2013; Boesdorfer & Greenhalgh, 2014; Wilson, 2013), it should not be unexpected that administrators are challenged by it as well. If science teachers struggle with NGSS terminology and implementation after study and PD, how can teacher evaluators be expected to understand what to watch for in a NGSS science lesson?

Implementation of the Next Generation Science Standards often requires schools to remove or, in some cases, add content to science courses to meet all standards for all students. One teacher in this study found that he had to remove a third of the pre-existing physics content in order to add in new content based on NGSS performance expectations. He explained the effect on his course, “Things you did that would reinforce ideas so people would understand it better were now replaced by something that was kind of related to what the unit was, but not as directly related.” He was concerned that students would not have an adequate foundation to understand the included content because reinforcing materials were eliminated in the interest of instructional time for the new content. Similar comments were voiced as my high school’s science department discussed the distribution of the standards among the existing high school science courses. There was also concern about the absence of many concepts from NGSS that veteran science teachers considered important to a complete understanding of a science discipline. In many instances our department decided materials that was not mentioned in NGSS was important to the remaining concepts and retained those ideas in the science curriculum. School districts and science departments should be aware of these concerns and ensure that the science content and instructional activities that remain in science courses support an understanding of science including the underlying skills that are not explicitly expressed in the NGSS performance expectations.

Recommendations for Practice

This was a qualitative multi-case study with three participants. Although generalization is not possible with this type of study (deMarrais & Lapan, 2004), the findings suggest some issues that science teachers, professional development facilitators, and administrators should consider when planning for science teacher professional development programs.

Terminology

Understanding the structure and goals of NGSS begins with understanding the terminology used to describe the instructional expectations and student skills that make up the standards. Teachers should understand that terminology: crosscutting concepts (CC), science and engineering practices (SEP), scientific argumentation, inquiry, and phenomena. This is important for all involved in science education but will be particularly important for any teachers new to NGSS: new teachers or teachers new to a school district or state using NGSS. Seven crosscutting concepts and eight science and engineering practices provide the framework for the K-12 science education; teachers should be aware of each of these items and emphasize their roles during instruction. Two of the teachers in this study, despite their science teaching experience, did not understand the ideas represented by the science and engineering practices; they thought that phrase referred to the engineering process and its applications. All science teachers, regardless of their experience level, would benefit from study of the crosscutting principles and science and engineering practices and how they relate to science teaching.

The crosscutting concepts and science and engineering practices are not new to science education; most are used regularly in science classrooms. Current science teachers do not have to change all their teaching practices; many of the instructional strategies teachers used before NGSS was implemented correspond to the CC and SEP described in NGSS. Teachers, and those who evaluate science teachers, need to understand NGSS terminology and realize how those can be demonstrated in the classroom. The importance of the interrelated nature of the CC and SEP and science content should be emphasized for all science teachers. Any gap in this awareness can be remedied at every level of teacher professional development. Each teacher, if they realize this is a personal concern, can review the NGSS terminology independently. Building and district professional development facilitators can increase NGSS language fluency by an emphasis on the terminology during department-specific PD programs. Classroom posters listing the crosscutting concepts and science and engineering practices could remind teachers and students to consider those ideas and skills.

Teaching Practices

Much of NGSS is familiar to science teachers; some teachers may attend to the changes to science content and overlook the other area of emphasis – the interrelated nature of the content with the crosscutting concepts and science and engineering practices. In many cases science teachers are already teaching in a manner that encourages students to recognize the crosscutting concepts and utilizes science and engineering practices. Professional development (PD) programs should encourage teachers to look beyond any content changes to the teaching of science. Teachers should be encouraged, whether independently or in a designated learning experience, to evaluate their own teaching practices and expectations and go beyond the commonalities of their practice with NGSS and identify the missing components. It would not be a surprise if some science teachers ignored NGSS PD and felt it was unnecessary. Professional development programs should consider the expertise of teachers and identify the needs of the population and the resources available within the group of teachers. The needs of the teachers must be addressed; the skill set of the current group of teachers may be able to be used as a resource for professional development. Kennedy (2016) explained that experienced teachers, those that have established teaching preferences, would have to give up that established teaching preference in favor of new strategies. For many teachers this will be a struggle unless they respect the value of the new strategies. The challenge to PD developers and building administrators is to identify ways to engage those who consider NGSS PD unnecessary and find ways to illuminate the similarities and differences between current teaching practices and NGSS strategies.

Scientific Argumentation

The teachers in this study identified scientific argumentation, an important objective of NGSS, as a weakness for their students. Grooms et al., (2015) explained that "Scientific argumentation is the process by which science, as a discipline, develops and refines knowledge" (p. 45). Scientific argumentation requires students to use evidence to make and defend conclusions. The teachers in this study expressed concerns about their students' attitude and ability to construct and defend scientific statements. The students were not willing to take and defend a position on a science idea and they could not argue based on observations.

Teachers should model the use of data to support and defend conclusions. The "claim, evidence, reasoning" framework (McNeill & Krajcik, 2011) can provide a supportive framework for teachers and students in the development of the skills of scientific argumentation. This framework supports scientific argumentation as students answer a specific question with evidence from observations or other data and provide an explanation of why that evidence supports the original claim. Once a student presents a "claim, evidence, reasoning" argument others can support or refute that claim by addressing the evidence or reasoning used to defend the original claim. Starting with a structured scientific argument framework like "claim, evidence, reasoning" provides a scaffold for those inexperienced in scientific argumentation to practice the skills required to defend scientific claims with evidence and reasoning. Professional development programs should provide all science teachers with more information about scientific argumentation and modeling of its use with students of all grades and abilities.

Scientific argumentation is important in the context of science. These skills, like those of the science and engineering practices, have value beyond the science classroom as students are preparing for college and career (see Appendix C) (National Research Council, 2013b). Students need to practice and build this skill.

Nonformal Professional Development

Nonformal professional development played a role in the learning opportunities of the teachers in this study although the value of a given PD topic varied depending upon the perceived needs of the teachers. Professional development designers need to identify the topics teachers need and want covered during the limited time available for professional development. Science teachers would benefit from programs focusing on NGSS terminology: crosscutting concepts and science and engineering practices. Scientific argumentation was identified by this study's teachers as a weakness; professional development programs could foster understanding of the idea and its application in the classroom. Science teachers are using many NGSS recommended practices in their classrooms. Nonformal PD programs could provide tools and support to teachers that would allow analysis of current classroom activities to find consistencies and gaps with NGSS science instruction.

Informal learning

Informal learning - particularly independent, self-directed study and collaboration - was identified as important for professional learning for this study's participants. Currently there is little acknowledgement of the time teachers invest in informal learning activities and the benefits from those experiences. School administrations should recognize the contributions of informal learning to teacher professional development and facilitate those activities through formal recognition and allotment of time in the professional development program for teacher-driven informal learning experiences. Teachers could authenticate informal learning with documents describing how time was spent and how those efforts influenced teaching practice or any aspect of their effectiveness as a teacher. Informal learning should be credited as part of each teacher's required continuing education program.

Recommendations for Further Study

This study was limited to the NGSS learning and implementation experiences of three veteran science teachers. Teacher participants self-identified; that led to common participant demographics – all three participants taught physical science or physics, all three participants held a master's degree in education, and all three participants came to classroom teaching through alternate certification programs. This study's methodology and the demographics of the participants suggest several areas of further study.

1. Duplication of this study with unrepresented science teachers — biology, chemistry, and earth and space science — would allow for comparison of the experiences of teachers in other science content areas.
2. Each participant was engaged with data collection for a period of three to four weeks. A longer study time, perhaps covering a semester or academic year, could provide more examples of transfer of NGSS knowledge to classroom practice.
3. One of this study's participants had moved to Kansas after teaching in a state that had not adopted NGSS for its science standards. This population, veteran teachers

moving from a non-NGSS state to a NGSS state, might offer different experiences than this study's participants.

4. This study's participants were volunteers; participants self-identified for this study. A similar study, in the form of a quantitative survey posing similar questions could minimize the impact of participant motivation.
5. This group of teachers did not routinely use the NGSS terminology of crosscutting concepts, science and engineering practices, inquiry, and scientific argumentation when asked to describe NGSS. An exploration of the relationship between language and teaching practices could provide information about any correlation between NGSS terminology and NGSS implementation.
6. Duplication of this study with high school teachers with one to three years' experience would provide a greater understanding of any differences based on teaching experience.
7. One of the teachers in this study expressed frustration with the requirement to incorporate earth and space science content in the physics course. The other two teachers did not have similar experiences with content requirements; although, they were each teaching physical science, not physics. NGSS and the Kansas Department of Education does not specify where schools must include the standards in the high school science curriculum. A study that explores district distribution of NGSS standards among high school science courses could suggest challenging and successful patterns of NGSS implementation.

Recommendations for Policy

A review of this study's findings leads to some suggestions that are beyond the ability of an individual classroom teacher or building administration to implement. These recommendations address science education at the district and/or state level and would require a review of existing practices or policies with attention to the influence of the Next Generation Science Standards on the K-12 science education program.

Transfer of Knowledge and Science Teacher Evaluation

Exposing teachers to professional development does not ensure that the teacher will convert that information to practice. Each teacher determines what information, knowledge, and teaching strategy transfers from a learning experience to the classroom (Enderle et al., 2014; Hewson, 2007). Veteran teachers are more likely to "have already developed their practice" (Kennedy, 2016, p. 3) and must deliberately move from that current practice to new methods. Teaching with NGSS incorporates existing science instruction strategies with additional emphasis on science and engineering practices, inquiry, and scientific argumentation (National Research Council, 2013a). Teaching practices should be evaluated with attention for evidence and NGSS teaching practices of inquiry, scientific argumentation, and the science and engineering practices. Observation of those practices provides evidence for the transfer of NGSS knowledge to classroom practice.

In most cases, building administrators are responsible for teacher evaluation. Assuming science teachers are evaluated with attention to the NGSS recommended teaching practices, it is critical that those evaluators are familiar with those ideas. The need for NGSS PD for all involved in education — state education department personnel, district and building administrators, and K-12 science teachers — was identified and advised (Harris et al., 2017;

National Research Council, 2015). Based on the comments from one of the teachers in that study, administrators are not receiving PD on NGSS. Administrative understanding of NGSS — the content, the crosscutting concepts, the science and engineering practices, and the associated classroom activities — is critical to appropriate evaluation of science classroom instruction, student success, and teacher performance.

Distribution of the Standards in Science Courses

The Next Generation Science Standards are complex. Teaching with NGSS affects all aspects of science instruction: teaching practice, assessment, curriculum materials and classroom activities (Next Generation Science Standards, 2015). In addition to these concerns is the distribution of the standards among a school's science courses. Appendix K (National Research Council, 2013b) of *Next Generation Science Standards: For States, By States (Vol. 2)* was written to provide advice to states and school districts as those organizations determine how to address the NGSS performance expectations within the high school science courses. Given the complexity of the standards, Appendix K included suggested modifications to much of the existing high school science curriculum. While these were only suggestions, these recommendations illustrate the challenges of including the high school standards within the traditional high school science curriculum.

The physics teacher in this study illustrated this challenge. He described omitting a third of the physics content originally in the course to incorporate new content, usually NGSS Earth and space science standards. The removal of such a large portion of the traditional physics content was frustrating to the teacher; he was concerned that his students would not have access to supporting material that would allow them to comprehend much of the remaining material.

Districts and states, if applicable, must give careful consideration to the distribution of the Next Generation Science Standards among the high school science courses. Teachers, in many cases, will be modifying existing science instruction even as they are incorporating new standards and new content into their courses. This is a complex task that must be carefully planned so that there is adequate science content foundation for the students and the teachers as new content is introduced.

Availability of NGSS Curriculum Materials

NGSS instruction requires a systemic modification to science education. As school districts and state education departments implement NGSS there must be provisions to provide updated, NGSS-compliant materials to science teachers. These instructional resources may not be readily available. New curriculum can be expensive; new curriculum may still be in development. Districts must provide classroom teachers with current resources if science teachers are expected to implement NGSS. If those resources are not provided the current classroom teachers must be allotted time and research materials to modify currently available curriculum to correspond to NGSS.

Conclusion

The Next Generation Science Standards (NGSS) provide a framework for K-12 science instruction in Kansas and 19 other states for the foreseeable future. Science teachers, particularly those who have been teaching for many years, have learned about NGSS through professional development. NGSS is a major shift in focus for many science teachers — stressing student development of knowledge over the K-12 education with an emphasis on cross-cutting concepts, science and engineering practices, and scientific argumentation. Many of the cross-cutting concepts and science and engineering practices are not new to science teaching. Many teachers routinely incorporate these ideas in science courses.

This research study explored the experiences of three veteran high school science teachers with NGSS learning and transfer of NGSS knowledge to teaching practice. The findings from this study suggest that teachers may not describe NGSS in terms of crosscutting concepts and science and engineering practices but those ideas are visible in the classroom strategies and learning tasks. Teachers regularly gain knowledge and insight from informal learning experiences, particularly self-directed study and collaboration. Nonformal professional development, usually district-provided workshops, is only beneficial if the teacher finds a specific need for that information. NGSS influenced teachers' selection of science content and classroom activities. Scientific argumentation, a central idea of NGSS, was a weakness for all teachers.

Teachers, professional development designers, and school administrators should consider the complexity of NGSS when preparing and requiring professional development programs. Attention to the language of NGSS and its place in the classroom should be incorporated in departmental programs. School administrators should recognize and credit informal learning, especially independent study and collaboration, for the important role it plays in teacher learning.

Successful implementation of NGSS depends on the classroom teacher's integration of the standards with existing pedagogy and development of new knowledge (Harris, Sithole, & Kibirige, 2017). This study reinforces that idea. Handing a teacher a copy of NGSS will not guarantee classroom instruction that fulfills the intent of NGSS teaching. Science teachers need to understand the goals and structure of NGSS; science teachers need to understand why those goals and structures are beneficial to student learning. Professional development staff and administrators must appreciate the challenges science teachers face as they modify curriculum and teaching practices to implement NGSS and provide regular support for that transition. School administrators need to recognize and reward the important contributions of informal learning to teaching practice. The teachers in this study had a variety of professional development, mostly nonformal and informal learning, and all developed their own ideas of how NGSS impacted their classroom activities and teaching practices. Attention to teachers' pre-existing ideas of science education is a critical component of any professional development designed to increase understanding of NGSS and its implementation in science classrooms. All three teachers transferred NGSS knowledge to classroom practice, except when it was inconsistent with a teacher's previous experiences or pre-existing teaching strategies. Implementation of NGSS content and teaching practices in every science classroom will require focused and sustained attention and professional development on all of the components of NGSS — content, crosscutting concepts, science and engineering practices, and scientific argumentation — for all science teachers.

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Appendix A

Dear ,

My name is Anne Krebs and I am a doctoral student in Kansas State University's College of Education in the Adult Learning and Leadership program. I am writing to invite you to participate in a qualitative research study about how science teachers are learning about the Next Generation Science Standards (NGSS) and how they transfer that learning into teaching practice. I am looking for current high school life science, physical science, integrated science or earth and space science teachers with at least five years' experience in the science classroom. I obtained your contact information from your school district's staff directory.

If you decide to participate in this study, you will be asked to participate in two interviews, provide documents relevant to NGSS learning and classroom instruction, and allow two observations in your classroom. If permissible, I will audio record the interview to facilitate transcription.

This study is voluntary. If you are interested in learning more about the study or would like to volunteer to participate please contact me at amkrebs@ksu.edu or 913-390-3615. If you know of other science teachers who might be interested, please pass along this email and my contact information.

Again, study participants must be

- Current life science (biology), physical science (or physics or chemistry), earth and/or space science, or integrated science teachers
- Have at least five years' experience teaching science

Participants will be asked to

- Participate in two (audio recorded) interviews
- Share documents pertinent to the study purpose
- Allow two observations in the classroom

Thank you for your time and consideration.

Sincerely,

Anne Krebs

Anne Krebs, M.A.E, Doctoral Candidate, Adult Learning and Leadership, Kansas State University

Appendix B

Informed Consent Form

PROJECT TITLE: Next Generation Science Standards: Veteran High School Science Teachers' Transfer of Learning from Formal, Nonformal, and Informal Professional Development

APPROVAL DATE: 12/26/18

PROJECT EXPIRATION DATE: 12/26/19

LENGTH OF STUDY: one month

PRINCIPAL INVESTIGATOR: Royce Ann Collins, Ph.D., Associate Professor, Adult Learning and Leadership, Educational Leadership Department

CO-INVESTIGATOR(S): Anne Krebs, Doctoral Dissertation Research

CONTACT DETAILS FOR PROBLEMS/QUESTIONS: Dr. Royce Ann Collins, (913) 307-7353 or Anne Krebs, (270) 498-3110

IRB CHAIR CONTACT INFORMATION: Rick Scheidt, Chair, Committee on Research Involving Human Subjects, 203 Fairchild Hall, Kansas State University, Manhattan, KS 66506, (785) 532-3224; Cheryl Doerr, Associate Vice President for Research Compliance, 203 Fairchild Hall, Kansas State University, Manhattan, KS 66506, (785) 532-3224

PURPOSE OF THE RESEARCH: The purpose of this study is to explore the formal, nonformal, and informal ways that veteran high school science teachers describe their learning about NGSS and how those teachers are transferring learning and the NGSS goals of inquiry, engineering practices, and scientific argumentation to the classroom.

PROCEDURES OR METHODS TO BE USED: If you agree to participate in this study you will be asked to take part in two semi-structured interviews, allow two observations of your teaching practices, and provide documents pertaining to your classroom instruction or professional development relevant to this study. You will be provided the opportunity to review all transcripts and field notes for accuracy.

RISKS OR DISCOMFORTS ANTICIPATED: There are no expected discomfort or risks related to this study. Participants may withdraw from the study at any time.

BENEFITS ANTICIPATED: This research will help inform teacher development specifically with the Next Generation Science Standards at the high school. The participant may gain insight into his or her own teaching strengths and weaknesses with science instruction and the Next Generation Science Standards.

EXTENT OF CONFIDENTIALITY: This study is confidential. Your name will not be used and all records will be kept private. You will be assigned a pseudonym. Any information linking you to this study will be removed in any reports generated from this study unless you specifically give permission otherwise. Research records will be stored securely and will be available only to the researcher, Anne Krebs.

IS COMPENSATION OR MEDICAL TREATMENT AVAILABLE IF INJURY OCCURS? No

TERMS OF PARTICIPATION:

I understand this project is research, and that my participation is completely voluntary. I also understand that if I decide to participate in this study, I may withdraw my consent at any time, and stop participating at any time without explanation, penalty, or loss of benefits, or academic standing to which I may otherwise be entitled.

I verify that my signature below indicates that I have read and understand this consent form, and willingly agree to participate in this study under the terms described, and that my signature acknowledges that I have received a signed and dated copy of this consent form.

PARTICIPANT NAME: ____

PARTICIPANT SIGNATURE: _______________________________________

DATE: ______________________

WITNESS TO SIGNATURE: ____

DATE: ______________________

Appendix C

This study lasted sixteen weeks. Table C includes a breakdown of the timeline for data collection, data analysis, and report preparation. Table C includes the role, if any, of the participant during each phase of the study.

Table C-3 *Study timeline*

Date	Project Item	Participant's Role
Week 1 – Week 3	Emails sent to potential participants	Communicate with researcher to volunteer
	Journaling	None
Week 3 – Week 5	Obtain administrator permission	None
	Confirm participation with volunteers	Communicate with researcher
	Journaling	None
Week 5	Participant first interview	Answer questions
	Collect documents	Provide documents
	Begin transcribing interviews	None
	Journaling	None
Week 6	Participant first interview	None
	Participant first observation	None – conduct class as usual
	Complete transcribing	None
	Member Check	Review interview transcript and observation field notes – provide feedback, if necessary
	Journaling	None
	Develop interview questions for second interview	None
Week 7 – Week 8	Participant second interview	Answer questions

	Participant second observation	None – conduct class as usual
	Begin transcribing interviews	None
	Journaling	None
Week 9 – Week 10	Finish transcriptions and field notes	None
	Member check	Review transcriptions and field notes
	Preliminary coding from data sources	None
	Peer review of codes	None
	Journaling	None
Week 11 – Week 14	First and second cycle coding of all data	None
	Triangulation of data	None
	Analyze findings	None
	Journaling	None
Week 15 – Week 16	Member check coding and themes	Provide feedback to researcher
	Continue data analysis	None
	Journaling	None

Appendix D

Table D-4 *Research questions aligned with data sources*

Research Question	Interview Questions	Participant Observations	Document Analysis
RQ 1. How do veteran high school science teachers understand NGSS?	Q. How did you learn science? Q. Describe the Next Generation Science Standards. Q. What does NGSS mean to your classroom, your teaching of science? Q. How do you describe learning through inquiry or inquiry learning? Probe: Describe an inquiry learning activity from your teaching. Q. How do you describe engineering practices in the science classroom? Probe: Describe an engineering practice or activity from your teaching. Q. How do you describe scientific argumentation in the science classroom? Probe: Describe an application of scientific argumentation from your teaching.	Inclusion of NGSS content components: performance expectation disciplinary core idea science of engineering practices crosscutting concepts Use of NGSS recommended teaching practices Scientific argumentation Learning through inquiry Engineering principles and applications	Statement of NGSS standards within lesson plans Lesson planning incorporation of engineering practices, scientific argumentation, and learning through inquiry

RQ 2. How do veteran high school science teachers describe their NGSS-focused experiences according to the classifications of formal, nonformal, and informal learning?	Q. Tell me about your professional development experiences. Probe: What was the setting of the PD? Probe: How long did the PD last? Probe: What was the purpose of the PD? Probe: What did you do during the PD? Q. Describe other experiences that you feel contribute to your teaching practice or content knowledge. Probe: Do you have someone you consider a mentor? Describe that relationship. Probe: What, if any, websites or online resources do you visit for teaching ideas? Why are those sources valuable to you? Q. Describe the PD you have received on NGSS content. Q. Describe the PD you have received on NGSS teaching practices. Q. Describe the best time you learned something that helped you implement NGSS. Q. What NGSS topics would you like to see in your next PD? Why? Q. Describe your preferred PD or learning environment or experience.		Professional development documents • Learning objectives • Content • Emphasis • Learning activities • Resources provided • Material referenced

RQ3. How do veteran high school science teachers transfer learning and modify teaching practices and science content as they incorporate NGSS specified inquiry, engineering practices, and scientific argumentation?	Q. Describe the best time you learned something that helped you implement NGSS. Probe: What made that experience so important? Q. Describe the changes you have made to your classroom or teaching practices since NGSS. Probe: How did you or your teaching change? Probe: Can you connect those changes to a specific experience or event? Q. What have you incorporated from your NGSS learning into your teaching practices? Q. What experiences do you consider important to your NGSS learning? Why? Q. Describe the process you use to decide what NGSS information or skills you utilize in the classroom.	Inclusion of NGSS content components: performance expectation disciplinary core idea science of engineering practices crosscutting concepts Use of NGSS recommended teaching practices Scientific argumentation Learning through inquiry Engineering principles and applications	Statement of NGSS standards within lesson plans Lesson planning incorporation of engineering practices, scientific argumentation, and learning through inquiry
	Questions for interview #2 were composed after the first interview and the first observation. Those questions followed up on the topics from the first interview and explored the choices behind the teaching practices utilized during the classroom observation.		

Appendix E

Observation Protocol

There will be two 50-minute observations of each participant during this study. The researcher will observe the participant during a science lesson. No student information will be gathered and there will be no recording during the observations. Field notes will focus on the science content and teaching methods employed during the lesson. The researcher will take field notes of the participants' actions, language choices, and teaching strategies.

The participants will have the opportunity to member check researcher field notes and will be invited to expand on his or her actions and choices during follow-up interviews.

No portion of the notes or transcripts will appear in the research study without the participant's written permission.

Observation field notes may include but are not limited to the following pieces of information:

- Setting description – physical location, materials and equipment available
- NGSS PE, DCI, SEP, and CC
- Teaching practices or methods, particularly scientific argumentation, inquiry learning, and engineering principles
- Participant's movement around the room
- Participant's comments and instructions to the students
- Activity – participant; participant/student
- Event – actions by participant resulting in behaviors/actions from students
- Time involved
- Attitudes or feelings displayed by participant or students

Appendix F

Observation Field Notes Template

Participant ID:	Class:
Date:	Time:
Time:	
Location:	
Topic:	
Room description **(include sketch)**:	

NGSS Performance Expectation (PE): **(if not explicitly stated describe lesson)**

NGSS Disciplinary Core Idea (DCI): **(if not explicitly stated describe lesson)**

Science and Engineering Practices (SEP):

- Asking questions and defining problems
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics and computational thinking
- Constructing explanations and designing solutions
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information

Crosscutting Concepts (CC):

- Patterns
- Cause and effect
- Scale, proportion, and quantity
- Systems and system models
- Energy and matter in systems
- Structure and function
- Stability and change of systems

Teaching practices:

- Scientific argumentation
    - Compare arguments
    - Evaluate explanations
    - Critique or receive critique on scientific argument
    - Question reasoning and evidence
    - Make or defend claims based on evidence
    - Evaluate competing design solutions

- Learning through inquiry
    - Student-generated question to be investigated
    - Student-designed experiment
    - Student-designed data analysis

- Engineering principles
    - Define a problem or issue of concern
    - Design a process, product or system to address the issue
    - Construct the solution
    - Evaluate the solution
    - Re-design or optimize the solution

Notes	Observations

Appendix G

Document Analysis Protocol

Documents have the potential to provide context to the researcher during qualitative studies. The participants were asked to share documents that might offer insight into the written guidance provided to students concerning science learning in the classroom and laboratory. The participants were also invited to share documents they considered relevant to their professional development experiences. These documents were used in this report only if there was no danger of revealing the participant or any other associated individual.

Documents included:

- Classroom handouts (including grading structure, laboratory guidelines)
- Lesson plans – including student handouts and grading rubrics
- Professional development materials
- Researcher reflection journal

These documents, together with the interview transcripts and observation field notes, were analyzed for themes and patterns related to the participant's description of NGSS and transfer NGSS knowledge to classroom practice. The documents were reviewed for language related to the crosscutting concepts (CC), inquiry, scientific argumentation and science and engineering practices (SEP) as well as assignment items that incorporated those ideas, skills, or practices.