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University-based Engineering Training of High School Science Teachers to Implement the Next Generation Science Standards (Work in progress)

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University-Based Engineering Training of High School Science Teachers to Implement the Next Generation Science Standards (Work in Progress)

Introduction

Science education in the United States is in the midst of a major reformation. The *Next Generation Science Standards* (NGSS), released in 2013, aim to improve K-12 science education through a renewed focus on scientific and engineering practices intertwined with recurring conceptual themes across the sciences [1]. The standards are based on the National Research Council's *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* [2]. Ultimately, the goal of the NGSS is to empower all students to participate in public science discourse, be critical consumers of scientific information, and have the skills to pursue careers in the 21st century, particularly those in science, technology, engineering, and mathematics (STEM) [2]. As an increasing number of states adopt the NGSS, there is mounting pressure to prepare science educators for the impending changes in expectations, curriculum, and assessment.

There are significant challenges as states transition their science standards to align with NGSS, such as insufficient professional development and support for teachers, inconsistency of implementation, and inadequate time and curricular resources [3]. In this recent reform effort, science teachers are likely to be inadequately prepared and lack the confidence to teach the engineering components of the standards, leading to avoidance or misrepresentation of the engineering practices in the classroom [4]. This paper describes the development of a professional development experience for science teachers designed to address these potential pitfalls and support the implementation of the NGSS in science classrooms. The overarching research question driving this work is: How do science teachers rate their self-efficacy in engineering knowledge and instruction, as well as the importance of engineering practices in learning science? This paper reports on theoretical foundations, pre-treatment data, and a novel intervention design for improving science teachers' engineering knowledge and pedagogical practices.

Theoretical Approach to Engineering Education Professional Development

Productive and accessible science teacher professional development, specifically in the field of engineering education, is necessary for the success of the mission of the NGSS. Effective professional development can increase the likelihood that teachers will follow through on implementation of this reform and ultimately influence student STEM achievement [5]. In response to this critical need, this engineering professional development experience will address science teachers' skills and attitudes towards engineering in the science classroom.

The NGSS aims to bridge the existing gap between K-12 science classroom experiences and the true experience of science in society and the workplace [1]. Consequently, central to the structure of the NGSS is an emphasis on science and engineering practices [1]. Additionally, the NGSS are designed around a unique three-dimensional approach. Dimension one focuses on the science and engineering practices that scientists and engineers employ in developing knowledge and solving problems. The second dimension identifies the crosscutting concepts, or themes, that are reflected throughout all domains of science. Dimension three identifies essential scientific knowledge required for basic literacy in science. This organizational shift away from conventional content-driven standards is meant to provide a more cohesive K-12 science experience and ensure that all students complete high school with the basic science and engineering literacy required for the 21st century [2]. This educational strategy is intended to improve motivation and performance in science, leading to more diversified accessibility to STEM study and careers (Figure 1).

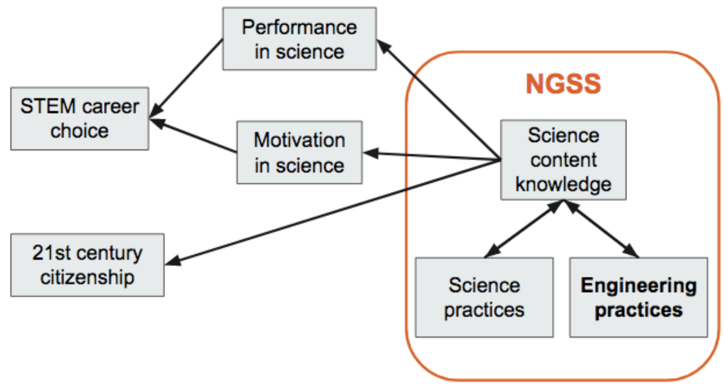

Figure 1: **NGSS structure and impacts on teaching and learning science.**

The NGSS aim to deepen student understanding of science through engagement in both science and engineering activities [2], [6]. Integration of engineering design in the science classroom has been shown to facilitate the development of science knowledge, logical thinking, communication skills, and holistic and discrete views of systems and processes [7]. The American Society for Engineering Education (ASEE) standards for teacher preparation in engineering education, which also served as a foundation for developing this course, focus on three key domains of engineering literacy for both teachers and their students: 1) engineering design, 2) engineering careers, and 3) engineering and society. These standards propose that engineering education must be founded on an understanding of the design process, with an emphasis on optimizing solutions to work within constraints [8].

Preliminary Data Informing Course Design

In order to maximize the effectiveness of the course structure, experienced secondary science teachers were given a pre-treatment survey modified from two existing validated, reliable questionnaires – the *Teaching Engineering Self-Efficacy Scale* [9] and the *Familiarity with Design, Engineering & Technology (DET) Survey* [10]. Relevant items were selected with the assumption that most respondents would have limited experience in teaching engineering design principles in a science classroom. These items would also provide the research team with baseline data on science teacher attitudes towards and preparedness for implementing NGSS.

Twenty-two secondary science teachers, 14 women and 8 men, responded to the survey with a range of teaching experience from 7-25 years and a mean of 15 years. Their primary subjects taught included biology (n=7), chemistry (n=8), Earth science (n=3), and physics (n=4). Items and response percentages are presented in Table 1. The science teachers indicated a strong interest in becoming more proficient in teaching engineering design, yet less confidence in their ability to do so effectively. Notably, they overwhelmingly agreed that they did not receive adequate pre-service training in teaching engineering design; this indicates the need for in-service professional development opportunities to improve teacher proficiency in helping students meet NGSS objectives. Teachers shared a commitment to communicate the importance of engineering through integrated instruction, and overall appreciation for the value of NGSS in improving science learning in an increasingly technological society. The teachers were largely neutral regarding whether their school districts supported efforts to incorporate engineering in science, suggesting that school leaders and administrators also require professional development regarding the importance of the standards in improving STEM education for all students.

Table 1

Science Teacher Responses to Engineering Teaching Efficacy Survey (N=22)

ITEM	SA	A	N	D	SD
Importance of engineering and design					
1. I would like to be able to teach my students to understand the use and impact of engineering and design.	48	39	9	4	0
2. I would like to be able to teach my students to understand the science underlying engineering and design.	48	52	0	0	0
3. In a science curriculum, it is important to include planning of a project.	52	43	4	0	0
4. I am interested in learning more about engineering and design through in-service workshops.	30	57	4	9	0
5. I am interested in learning more about engineering and design through college courses.	27	26	26	17	4
6. I am interested in learning more about engineering and design through peer training.	30	43	22	4	0
7. I would like to be able to teach my students to understand the design process.	52	35	9	4	0
8. I would like to be able to teach students to understand the types of problems to which engineering and design can be applied.	57	35	9	0	0
9. Engineering and design have positive consequences for society.	83	13	4	0	0
10. I support the integration of engineering and design in the K-12 curriculum.	57	35	9	0	0
11. In a science curriculum, it is important to include the use of engineering in developing new technologies.	57	26	17	0	0
Familiarity and self-efficacy with engineering content knowledge					
12. I feel confident about integrating more engineering and design in my curriculum.	17	39	17	22	4
13. I can describe the process of engineering design.	17	30	26	22	4
14. I can explain the ways that engineering is used in the world.	22	48	26	4	0
15. I can discuss how engineering is connected to my daily life.	26	48	17	9	0
16. My pre-service training was effective in supporting my ability to teach engineering and design at the beginning of my career.	9	0	4	48	39
17. I use engineering and design activities in the classroom.	4	35	17	30	13
18. I am familiar with the *New York State P-12 Science Learning Standards.*	39	35	17	4	4
19. My school supports my use of engineering and design activities.	13	30	43	13	0

Response codes: SA = strongly agree, A = agree, N = neutral, D = disagree, SD = strongly disagree

Course Structure

In response to preliminary data, teacher participants will be challenged to augment their existing science pedagogical content knowledge with new knowledge of engineering design and pedagogy. The professional development experience will not only introduce teachers to the disciplinary principles associated with engineering but also support them in integrating that knowledge with their science course content. In doing so, teachers will develop an understanding of the engineering process and identify relevant applications of design in their science curricula.

Contextual factors. Teacher participants in the planned study will be enrolled in *Introduction to Engineering Education*, a graduate-level engineering education course offered for science teachers in the summer of 2018. Teacher participants will be solicited from a variety of school districts located throughout Long Island, New York. To qualify for a high school diploma in New York State, general education students in public schools are required to complete three credits of high school science. One course of instruction must be in the life sciences, one in the physical sciences (Earth science, physics, or chemistry), and the third may be any designated science course. There is no requirement for students to complete coursework in either technology or engineering. Long Island science teachers are unique in that most are certified in at least two science disciplines; for example, the majority of chemistry teachers in the region have a primary certification in biology [11]. Middle school science teachers are often required to teach all of the science disciplines in a spiral curriculum consistent with NGSS, and all science teachers need to emphasize crosscutting concepts that link disciplinary domains [1]. New York State science teachers must demonstrate disciplinary competence in all four basic sciences to earn a 7-12 teaching license [12]. Consequently, a professional development course that incorporates engineering practices in more than one science discipline is both desirable and necessary to meet the needs of Long Island teachers and their students.

Refining and building upon prior professional development models. Although there have been many published works on general principles of effective teacher professional development for meeting NGSS standards [4], [13]-[15], as well as assessing lesson alignment and developing performance expectations [16], [17], few researchers have provided empirical support for specific teacher training regarding integration of science and engineering for a yearlong course at the secondary level. This is particularly important for science teachers in New York State since all high school and many middle school students take high stakes cumulative exams, known as Regents exams, to measure whether they meet state standards. This newly designed graduate course will provide secondary science teachers with affordable, rigorous engineering activities, while equipping teachers with the tools to develop NGSS- and state-aligned curricula in several science domains. Some of the activities have been previously piloted and evaluated with middle and high school students in the researchers' outreach programs [18]-[21]. Teachers will have numerous opportunities to collaborate with peers and engineering professionals to draw connections between engineering principles and relevant science content. Previous research has shown that this model for professional development increases program efficacy [22].

Session activities. This course was developed as a collaboration between university science education and engineering faculty based on recent literature regarding high quality teacher professional development. As such, the course will focus specifically on the engineering design principles that are emphasized throughout the NGSS [1] and ASEE standards [8]. Class sessions will be co-taught by science education and engineering faculty. To maximize broader impacts, the course will be presented in three modules: 1) electrical engineering co-taught with physics education faculty; 2) materials science and chemical engineering co-taught with chemistry education faculty; and 3) biomedical engineering co-taught with biology education faculty.

Devices built in the physics/electrical engineering unit will be used to test materials in the chemistry/materials science and biology/biomedical engineering units. Each module will address disciplinary core ideas, crosscutting concepts, and science and engineering practices through theory-based readings and discussions, hands-on tasks, and collaborative curriculum design. Consistent with NGSS, activities are framed for identifying problems and defining related limitations and criteria for technological advancements. Teachers will generate and evaluate a variety of solutions to identified problems. Finally, they will optimize solutions through analysis of the value and costs associated with their designs [1]. Sample course activities are described in Table 2.

Table 2
Sample Course Laboratory Activities Developed by Research Team

Disciplinary Ideas & Crosscutting Concepts	***Engineering Practices***
Physics and Electrical/Computer Engineering • DC circuits and electromagnetism • Induction, phase response, oscillator and transistor function • Energy transfer	Teachers will design and construct metal detectors [19]. Assembled devices must meet constraints regarding cost, efficiency, and component function. Teachers will optimize their devices to vary sensitivity and frequencies depending upon metal conductivity.
Chemistry and Materials Science • Physical and chemical properties of matter • Data acquisition and analysis with Matlab • Quantifying material stress and strain at various temperatures.	Teachers will test a series of metallic glasses. They will study the utilization of engineered metallic nanostructures in design. They will learn how optimization techniques are implemented in modern research and development laboratories.
Biology and Biomedical Engineering • Microorganisms • Cell structure and function • Optics and light transmission	Teachers will design and print (3D) lenses to fit on their cell phones to serve as a microscope [23]. The devices will be optimized for both brightfield and darkfield microscopy. Teachers will design relevant applications to view both cell nuclei and dynamic organism activity using photo and video functions.

Future Directions

The university-based engineering and science education team will perform empirical analyses to measure programmatic impacts. Science teachers will be surveyed immediately after participation, and they will be observed and interviewed during the subsequent academic year to analyze in-service successes and challenges in implementing NGSS. A convergent mixed methods parallel design is planned to measure longitudinal impacts on teachers and students. These formative qualitative and quantitative data will inform future course offerings in engineering education. We plan on expanding science teacher offerings in the future to include other engineering disciplines in an effort to build capacity and the knowledge base for effective implementation of engineering practices in science education.

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