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A Survey of Utah's Public Secondary Education Science Teachers to Determine Their Feelings of Preparedness to Teach Engineering Design

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A SURVEY OF UTAH'S PUBLIC SECONDARY EDUCATION SCIENCE

TEACHERS TO DETERMINE THEIR FEELINGS OF PREPAREDNESS

TO TEACH ENGINEERING DESIGN

by

R. Tyler Ames

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Technology and Engineering Education

Approved:

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UTAH STATE UNIVERSITY
Logan, Utah

2014

ABSTRACT

A Survey of Utah's Public Secondary Science Teachers to Determine

Their Preparedness to Teach Engineering Design

by

R. Tyler Ames, Master of Science

Utah State University, 2014

Major Professor: Dr. Edward Reeve
Department: Applied Sciences, Technology, and Education

The Next Generation Science Standards were released in 2013 and call for the inclusion of engineering design into the science classroom. This integration of science and engineering is very exciting for many people and groups in both fields involved, but a good bit of uncertainty remains about how prepared science teachers feel to teach engineering design. This study analyzes the history of science standards leading up to the Next Generation Science Standards, establishes key components of the engineering design, and lays the background for the study detailed in this report. A survey was given to several hundred public secondary science teachers in the state of Utah in which respondents were asked to report their feelings of preparedness on several aspects of engineering design. The findings of the study show that Utah teachers do not feel fully prepared to teach engineering design at the present time (2014).

(73 pages)

PUBLIC ABSTRACT

A Survey of Utah's Public Secondary Science Teachers to Determine

Their Preparedness to Teach Engineering Design

by

R. Tyler Ames

Education is always changing and science education is no exception, with many influential publications passing through science education over the years. The latest wave in science standards is called the Next Generation Science Standards. The Next Generation Science Standards are anticipated to have a significant effect on state science standards around the entire country. One thing about these new standards is very different from all previous science standards—they include the principle of engineering design in them.

Asking science teachers to teach engineering design is asking them to teach a principle for which their teaching licensure would not have formally prepared them. Consequently, the hypothesis of this study was that the feeling of preparedness to teach engineering design would be low among public secondary education Utah science teachers. This study shows that hypothesis to be correct: Utah science teachers do not feel prepared to teach engineering design. The feelings of teacher preparedness can be improved through professional development and inclusion of engineering design into science teacher education programs. It should be infused into these arenas now that teachers have indicated their low feelings of preparedness. More teacher preparation should be sought because an unprepared teacher will not prepare students as well as a prepared teacher. And, creating prepared students is the goal of the education system.

DEDICATION

To Lauren and Madison

ACKNOWLEDGMENTS

I appreciate this opportunity to thank those who have been so instrumental in enabling the completion of this work. It all begins with my stalwart wife, Lauren. The value of her constant support and encouragement cannot be overstated. Thank you for all of the hours and emotion and willpower that you imparted to me.

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R. Tyler Ames

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LIST OF ACRONYMS

NGSS—Next Generation Science Standards

NRC—National Research Council

SFAA—Science For All Americans

STEM—Science, Technology, Engineering, Mathematics

CHAPTER I

INTRODUCTION

Background and Setting

The vast majority of Americans are familiar with public school. In fact, approximately 90% of all American children attend public school (National Center for Education Statistics, 2014). That means that 9 out of 10 children are in educational institutions that are trying to provide an education commensurate with state and/or national education standards. With such a large portion of tomorrow's youth passing through the public educational system, the curricula and content must be developed to meet high-quality standards. In an attempt to improve the science education available to all Americans, prominent science educators from around the nation convened to create science standards that are "rich in content and practice" (Next Generation Science Standards [NGSS], 2013c, p. 1). These new standards are called the Next Generation Science Standards (NGSS).

A principle found in the NGSS is engineering design. This principle is new to science curricula. The NGSS emphasizes integrating engineering into science education. In fact, the NGSS is making a commitment to fully integrate engineering into the structure of science education by raising engineering design to the same level as scientific inquiry in the classroom. In the NGSS, the core ideas of engineering are given the same status as core ideas in the other major science disciplines and they promote using the "engineering design" problem solving process.

Previous to the publication of the NGSS, only 12 of the 50 states in the U.S. had any mention at all of engineering in their science standards (Carr, Bennett, & Strobel, 2012). A direct result of such sparse science and engineering pairing is that engineering design will be a new concept for many science teachers. Despite its novelty, this type of inclusion is exactly in line with the recommendation of the National Academy of Engineering (NAE) for the promotion of engineering education in the U.S. (NAE, 2010).

Statement of the Problem

The combination of science with engineering seems like a competent pairing, but just how prepared do science teachers feel to teach the principles of engineering design? Those weighing in on the issue at this immature stage of NGSS implementation seem to agree that science educators are not prepared to teach engineering design yet (Banilower et al., 2013; Johnson & Cotterman, 2013; International Technology and Engineering Educators Association [ITEEA], 2012).

Do secondary science educators in Utah feel prepared to teach the engineering design process in their science classrooms? Do they recognize the difference between the aims of science and the aim of the engineering design process? And do they exhibit any inclination towards the delivery method of technology and engineering education? The following hypotheses were used in this study.

H_0: 80% of public secondary education science teachers in Utah feel either prepared or very prepared to teach engineering design in their science classrooms.

H_1: Less than 80% of public secondary education science teachers in Utah feel

either prepared or very prepared to teach engineering design in their science classrooms.

Research Questions

The objective of this study was to capture a general picture of the current state of Utah secondary science teachers' feelings of preparedness as it relates to teaching the engineering design process. The following questions will be addressed.

1.   Do secondary school science educators in Utah feel prepared to teach engineering design as measured through practices identified in the *Framework for K-12 Science Education* (National Research Council [NRC], 2012)?

2.   Do science teachers recognize the difference between the aims of science and the aim of the engineering design process (NRC, 2012)?

3.   Do science educators exhibit any inclination toward the delivery method of technology and engineering education in teaching engineering design?

This study established clear and generally agreed-upon elements of the engineering design process in the literature review and reports on a survey of secondary science educators from the state of Utah that was given to find out about their knowledge of engineering design and their perceived capacity for using said design process. All of this will lead to a general picture of science teacher preparedness as it relates to teaching the engineering design process. The study hypothesized that responses from science teachers would indicate a low perception of preparation to teach engineering design.

Significance of the Study

The importance of these findings will be useful to K-12 administrators, science teachers, science teacher educators, and others (e.g., curriculum developers and commercials vendors) involved with science education. The need for teacher expertise is generally agreed upon, and seems to be a foregone conclusion in the mind of any parent with a child in the public education sector. To understand the fervor with which parents demand quality teachers, one needs only attend a public parent-teacher conference night. The quality of science education—including the small but burgeoning facet of science education that now includes engineering design—should be of importance to all K-12 school administrators concerned with the level of education at their institutions. Upon receiving the results of this study, administrators should be able to better make decisions in supporting relevant professional development for existing teachers, in hiring teachers with necessary competencies, and in evaluating teacher adherence to standards. University faculty involved with science teacher education will also benefit by being able to identify which areas of their curriculum should be further developed and/or given additional emphasis during their work with preservice science educators.

Limitations

1. This study was limited to secondary education science teachers in Utah.

2. This study was limited to collecting data via an online survey instrument.

3. This study is specifically to determine science educators' feelings of preparedness to teach the engineering design process. It is not designed to evaluate the

quality of teaching or measure areas of content knowledge outside of the engineering design principle.

Assumptions

1. Science teachers answered the questions honestly.

2. Teachers who participated in the study have a background and training in science education.

3. Each science teacher only completed the survey one time.

Definition of Terms

Engineering design: The process that engineers undertake to solve problems by designing solutions. It is a process focused on finding solutions that work and is not tied to a single correct answer. The consensus elements of the engineering design process are identified in the literature review found in Chapter II.

The scientific method: A process used to determine why things happen by finding the best explanation. It is a process that is focused on explanations.

Next Generation Science Standards (NGSS): A set of science standards that was released in 2013. They are both intended and expected to influence science standards across the U.S.

CHAPTER II

REVIEW OF LITERATURE

In this review of literature an overview of science education in the U.S. since the middle of the 20th century will be given. The current state of engineering standards in public education will be analyzed. Justification for the inclusion of engineering design into the Next Generation Science will be given. The current ability of the science education community's ability to teach engineering design will be estimated and engineering design will be defined in depth.

Science Education

Education reform is not new and will never be truly completed (American Association for the Advancement of Science [AAAS], 1989, p. 5). In 1956, science education reform took a substantial step forward when Jerrold Zacharias began the Physical Science Study Committee. One year later, the USSR launched Sputnik and the science educational reform movement of the era planted itself firmly in the forward direction. Previous to Sputnik the prevailing sentiment that became popular after world war two had been a need to go "*back*—back to fundamentals, back to basics, back to drill and memorization, and back to facts" (Bybee, 2013, p. 13). With the launch of Sputnik, the U.S. pushed itself into a more uniform and forward-moving science education reform. This was spurred on by President John F. Kennedy's clear goals for the country to go to the moon. He summoned Congress for a joint session in 1961 and laid out a clear view of his goal to land a man on the moon before the decade was through (Kennedy, 1961). He

understood that science needed to take several steps forward to make this possible, as

evidenced by his speech at Rice University in 1962:

> We choose to go to the moon. We choose to go to the moon in this decade and do the other things, not because they are easy, but because they are hard.... The growth of our science and education will be enriched by new knowledge of our universe and environment, by new techniques of learning and mapping and observation, by new tools and computers for industry, medicine, the home as well as the school.... We shall send to the moon, 240,000 miles away from the control station in Houston, a giant rocket more than 300 feet tall, the length of this football field, made of new metal alloys, some of which have not yet been invented, capable of standing heat and stresses several times more than have ever been experienced, fitted together with a precision better than the finest watch, carrying all the equipment needed for propulsion guidance, control communications, food and survival, on an untried mission, to an unknown celestial body, and then return it safely to earth, re-entering the atmosphere at speeds of over 25,000 miles per hour, causing heat about half that of the temperature of the sun...we must be bold. (Kennedy, 1962)

The U.S. landed Neil Armstrong and Buzz Aldrin on the moon in 1969 with

Armstrong declaring those famous words, "One small step for man, one giant leap for

mankind." It is clear from the feat of landing a man on the moon that science moved

forward as a whole. But science education also moved forward with it. Students who

engaged in the new science curricula that was introduced in that era "performed better

than students in traditional courses in general achievement, analytic skills, process skills,

and related skills (reading, mathematics, social studies and communication), as well as

developing a more positive attitude toward science" (Shymansky, Kyle, & Alport, 1983).

Science education was moving forward and improving at that time.

A little more than a decade after the moon goal was complete, a study conducted

by the National Commission on Excellence in Education was published that painted a far

grimmer picture. The committee, comprised of distinguished and veteran educators, was

commissioned to study the quality of American education. They found results that were

much worse than anticipated (Bell, 1993, p. 593). The 1983 report, *A Nation at Risk*,

concluded:

> If an unfriendly foreign power had attempted to impose on America the mediocre
> educational performance that exists today, we might well have viewed it as an act
> of war.... We have even squandered the gains in student achievement made in the
> wake of the Sputnik challenge. Moreover, we have dismantled essential support
> systems which helped make those gains possible. (U.S. National Commission on
> Excellence in Education, 1983, p. 9)

The national regression and loss of previous gains was reiterated and confirmed

by another publication, released in 1989, that soon became a landmark in science

education entitled Science for All Americans (SFAA). The report called attention to the

most recent National Assessment of Education Progress report, published in 1986, that

found that "despite some small recent gains, the average performance of 17-year-olds in

1986 remained substantially lower than it had been in 1969" (AAAS, 1989, p. 2).

Science for All Americans (AAAS, 1989) emphasized the need for science

"literacy." The reasons given in the report for demanding science literacy range from

national self-interest, to individual self-fulfillment, to global necessity in the face of

problems like acid rain, a growing global population, and shrinking of tropic rain forests.

The stumbling block to a solid national science education effort appeared to be crushing

teaching loads, absence of a modern support system, and overstuffed and undernourished

science curricula. In order to provide more focus and encourage efficiency the report

gave several recommendations in the form of chapters. Each chapter presented a "major

set of related topics" (p. 6) that teachers were encouraged to draw from. The publication

was not intended to be used as a curriculum document or a textbook, but to inform

teachers of appropriate learning goals.

Immediately after its release, six teams were formed which were comprised of 25 teachers and administrators to study ways that science literacy goals could be attained. These teams worked for four summers and three academic years to produce a follow-up publication to SFAA and culminated with the printing in 1993 of Benchmarks for Science Literacy. Benchmarks for Science Literacy was intended to be used alongside of SFAA and to complement it. "SFAA presents a vision of science literacy goals for all students to reach by the time they finish the 12th grade, and Benchmarks maps out the territory that students will have to traverse to get there" (AAAS, 1993, p. 3). Benchmarks did not try to be a curriculum of any sort, but was a tool for educators creating curriculum. It purposely sheds only partial light on how one might attain the different goals expressed in the publication. And finally, the Benchmarks were built on a deep foundation of research—namely all "the relevant research literature in the English language (and some in other languages)" (AAAS, 1993, p. 4).

Largely influenced by both SFAA and Benchmarks, and at the request of the National Science Teachers Association (and with the encouragement of the U.S. secretary of education), the NRC produced the first ever science standards in the U.S. (NRC, 1996, p. 14). Published in 1996 and entitled *National Science Education Standards*, teachers had access to standards that detailed "what students should know, understand, and be able to do in the natural sciences over the course of K-12 education" (NRC, 1996, p. 6).

A decade and a half passed and important advancements both in science and the student learning process took place (NGSS, 2013c). Owing to the desire to improve

education (NRC, 2012, p. 1) the NRC convened to discuss the national science standards and in 2012 published *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. The *Framework for K-12 Science Education* was produced upon "a rich and growing body of research on teaching and learning in science, as well as on nearly two decades of efforts to define foundational knowledge and skills for K-12 science and engineering" (NRC, 2012, p. 2).

The NRC (2012) asserted in the *Framework for K-12 Science Education* that K-12 science education "is not organized systematically across multiple years of school, emphasizes discrete facts with a focus on breadth over depth, and does not provide students with engaging opportunities to experience how science is actually done" (p. 1). To overcome these shortcomings, the publication suggests focusing, as the title suggests, on three categories of science education: practices, crosscutting concepts, and a limited number of core ideas. It recommended that each standard be focused around those three things and that the focus be put upon quantifiable performance instead of the nebulous goal of "understanding" (NRC, 2012, pp. 218-219). Four disciplines for K-12 students to learn about were selected: physical sciences; life sciences; earth and space sciences; and engineering, technology, and applications of science. Each discipline would contain multiple standards and each standard would be broken up and presented in the three dimensions discussed above, with an overarching emphasis in performance.

The action that the Framework for K-12 Science Education called for began—expert committees were formed, lead states were selected and several iterations of new standards were produced, critiqued, and refined over the course of 2 years (NGSS,

2013a). With that, the new standards were born in April of 2013.

The release of the NGSS is timely and coincides with a national push for more science, technology, engineering, and mathematics (STEM) education. Large companies in the private sector are giving large sums of money away in grants. Google supports the development of a national STEM teacher corps and gave $40 million in STEM grants in 2011 (Koebler, 2011). The Toyota USA Foundation donated $1.3 million in STEM grants (Toyota, 2012). President Barack Obama stated, "Leadership tomorrow depends on how we educate our students today—especially in science, technology, engineering and math" (Sabochick, 2010, p. 1). One reason for President Obama's support is clear— while all jobs are projected to increase 14% by the start of 2020, jobs in the STEM realm range in projected growth from 16% to 62% (U.S. Department of Education, 2014). The national 2014 budget reflects the support of the presidential administration as $3.1 billion will be put into STEM education (White House Office of Science and Technology Policy, 2013).

The push for STEM is also seen throughout the state of Utah. In 2013 the state legislature voted to put $10 million toward the creation of a state STEM center with the goal of improving STEM education in Utah (Utah State Legislature, 2013, p. 14). A fully staffed STEM center was started in 2013 and has begun to tackle many of the governor's goals. One year later, in 2014, another bill was passed that dedicated $20 million to the state STEM center (Utah State Legislature, 2014, p. 2). The governor's stated goal was that 90% of K-12 students will be "at grade level" in STEM subjects. The state even began making efforts to have schools with STEM School status (Utah Technology

Council, 2013).

However, while STEM jobs are anticipated to increase, the U.S. appears to be unready for the growth. National test scores in science and math are merely average when compared with test scores of the rest of the developed world (Ames, 2014; Bybee, 2013). There are two globally recognized tests that are appropriate in this context: the Program for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMMS). The international tests used to test these areas have their critics and while it is not the intent of this paper to accredit or discredit the tests, the results appear to be fairly clear in one regard—The U.S. is not the global leader (Ames, 2014, p. 52)

In response to the need for improved K-12 STEM education (which need is benchmarked by the international test scores discussed above), many of the disciplines represented by STEM created or refined standards that are to be used in the teaching of STEM subjects. For example, in mathematics there is a set of standards known as the common core that is being pushed toward nation-wide acceptance. In technology and engineering education the *Standards for Technological Literacy: Content for the Study of Technology* (STL) were released in 2000 and endorsed by William A. Wulf, then-president of the NAE. In the foreword of the STL, Wulf encouraged all K-12 teachers across all disciplines to use the STL (ITEA, 2000, p. vi). Engineering does not have K-12 standards (though many engineering principles are included in the standards used by technology education). The NGSS were published in 2013.

Engineering Standards

The NAE visited the topic of engineering standards to determine if K-12

engineering standards should be created. According to their research, since the year 1990,

5 million K-12 students have participated in "formal engineering curricula" (p. 6; though

they gave no definition for what such formal engineering curricula refers to). The NAE is

quick to point out that this is a small number when compared to the roughly 56 million

students that are enrolled every year in the U.S. K-12 educational system. What it does

point out is that engineering education is receiving more emphasis in the K-12 system

than previously. Ultimately, the NAE concluded that the present time is not the right time

to introduce stand-alone engineering standards—citing an unfilled "critical mass" of

engineering educators—and recommended that engineering standards be integrated into

national standards for other content areas. Its infusion into another subject would be a

"step toward putting engineering on par with other school subjects in the eyes of students,

educators, and the public" (NAE, 2010, pp. 23-24).

Next Generation Science Standards

The standards found in technology and engineering education have infused

engineering design already, but its simultaneous infusion into the NGSS is a substantial

step toward the stated goals of the NAE for engineering education. The NGSS's inclusion

of engineering is a logical step forward in the progression of adequate standards.

Previously, engineering standards have existed in local standards on a state-by-state

basis. While most states (39) have high school level engineering curricula of some sort,

only 11 have explicit standards for engineering. An analysis looking for any existing state engineering standards across all 50 states revealed that across all engineering-related curricula the word "design" was the most commonly used engineering-related word. It was, in fact, used very nearly twice as often as any other engineering related word across the entire curricula base of the U.S. (Carr et al., 2012). Furthermore, the NAE analyzed eight different scholarly papers that all claimed to identify the core concepts of engineering. The only core concept identified by all eight of them was design (NAE, 2010). It is appropriate, then, for Engineering Design to be the first engineering standard introduced into national science curricula.

The combination of engineering and science is an important step in moving engineering education—and thereby STEM education, forward. It is a mutually beneficial inclusion that makes sense in both practical and inspirational realms as students, tomorrow's leaders, will need to confront today's important and vexing societal and environmental challenges in the decades to come (NGSS, 2013d).

> We anticipate that the insights gained and interests provoked from studying and engaging in the practices of science and engineering during their K-12 schooling should help students see how science and engineering are instrumental in addressing major challenges that confront society today, such as generating sufficient energy, preventing and treating diseases, maintaining supplies of clean water and food, and solving the problems of global environmental change. (NRC 2012, p. 9)

It is not only a way for engineering education to expand but also a way for STEM areas to move towards coherence and be taught together, which is an important best-practice in any STEM learner's education (Bybee, 2013, p. 29; Reeve, 2013). In 2011, and in response to a request from the National Science Foundation (NSF) to find high

performing STEM schools, the NRC published *Successful K-12 STEM education*, which identified successful traits of STEM education and gave nine recommendations for improving STEM education generally (NRC, 2011). Soon after its publication the U.S. Congress asked the NSF to identify ways in which progress towards those nine recommendations could be tracked. The NRC again convened and in 2013 published a follow-up work, *Monitoring Progress Toward Successful K-12 STEM Education* (NRC, 2013a). In the follow-up, the committee identified 14 indicators that could be used to track the progress of the nine original recommendations. Six of the indicators were printed in bold so as to "reflect the committee's highest priorities." Two of those six indicators for "highest priorities" relate intimately to the implementation and inclusion of engineering into the NGSS.

> High priority indicators, as recommended by the NRC, are needed for:
>
> 1. Teacher's science and mathematics content knowledge for teaching.
> 2. Classroom coverage of content and practices in the...Next Generation Science Standards. (p. 2)

These two indicators, as they relate to engineering design in the *NGSS,* show that the teaching of engineering design in the science classroom, and the preparation of those teachers to teach it are some of the highest priorities in the STEM field. Taking a closer look at the first of those two indicators, teacher content knowledge is an important factor in a teacher's ability to teach at a high level. Trying to grasp a teacher's content knowledge level is difficult and unreliable when analyzing the course load of teacher education programs in colleges (Wilson, Floden, & Ferrini-Mundy, 2002). Yet looking to a teacher's formal training is often how content knowledge is currently assessed. A much

better indicator than the courses that teachers took in college is a teacher's self-rating of their content knowledge. As long as no "stakes" are attached to a self-reported capacity to teach certain topics, those self-reported results have been shown to reliably measure content knowledge (PROM/SE, 2006).

Teaching Engineering Design in Science

While engineering design is a new standard in many science classrooms, it is not new to the technology and engineering education classroom. It has been in schools for many years and has been identified as one of the core standards to be taught by technology teachers (ITEA, 2000, pp. 99-105). But with the introduction of engineering design into science curricula, many suggest that science teachers do not have the necessary content knowledge and are currently unprepared to teach this new standard. Horizon Research recently published their finding that only seven percent of science educators feel "well prepared" to teach the new engineering standards (Banilower et al., 2013, p. 26). This cannot be a surprise when only 12 of the 50 states had their engineering curricula associated at all with science, and all the others with engineering standards (except Mississippi) merging into other interrelated categories like technology, technology and engineering, STEM, and vocational (Carr et al., 2012). Indeed previous to the NGSS, most engineering standards were taught by technology teachers and not by the science teachers who will be implementing the NGSS. Keeping a close eye on the future of engineering standards is the International Technology and Engineering Educators Association (ITEEA). This group expressed that in their view "the science community

will have a difficult time of addressing these [engineering] standards with their current

teacher workforce" (ITEEA, 2012). The most prepared teacher workforce to deliver

instruction on engineering design might well be the technology and engineering

education community, but it lacks the critical mass of teachers to deliver it to all students

everywhere. Many of the top national leaders in technology and engineering education

are excited by the opportunity to collaborate and work together with science educators to

deliver classroom instruction on engineering design (E. Reeve, personal communication,

April 8, 2014).

The concern about current preparedness to deliver engineering design instruction

also emanates from the science education community itself; the monthly report for the

National Science Teacher Association (NSTA) in November of 2013 ran a commentary

from science education faculty at Vanderbilt University expressing their concern that

science teachers are not prepared.

> With the release of the (NGSS), it is clear engineering education will need to play
> a more prominent role in K-12 science classrooms. This creates a dilemma as a
> second missing "E" is all too often in engineering education: *"expertise."* (*italics*
> in original; Johnson & Cotterman, 2013)

A very likely outcome when teachers feel underprepared is that the subject will be

altogether neglected. Perhaps the NRC was thinking of this very possible and very poor

"solution" when they recommended, as a high priority, the indicator "Classroom

coverage of content and practices in the...Next Generation Science Standards." In the

NRC's explanation, they stated that "considerable research and development efforts are

needed to develop measures for the coverage…of content and practices in engineering,

science, and career and technical education" (NRC, 2013b, p. 21).

Engineering Design

Science teachers currently teach a related process—the scientific method. The scientific method and engineering design method both seek knowledge through a structured inquiry but vary from each other in fundamental objectives. The scientific method is concerned with what *is*, but the engineering design process seeks to find what *will be* (Holtzapple & Reece, 2005, p. 21). The NGSS recognize the difference in their appendix saying, "the practices of engineering have much in common with the practices of science, although engineering design has a different purpose and product than scientific inquiry" (NGSS, 2013b, p. 1).

> Similar to the engineering design process, the scientific method is a series of steps used to solve problems. However, because the goal of the scientific method is not to design or create solutions, the steps are different from those of the engineering design process. (Brown, Brown, & Berkeihiser, 2014, p. 24)

The *Framework for K-12 Science Education* is very clear that while science and engineering both endeavor to find answers, the goal of each is slightly different. Science aims to explain phenomena and engineering seeks to address a human need or want (NRC, 2012, p. 47). An understanding of the difference in goals can be reinforced with a sound understanding of design. Mark Horenstein of Boston University defined design as "any activity whose objective it is to meet a need. The object of design might be a physical device, such as a machine or building. Alternatively, the objective might be something less tangible, such as . . . process control" (2010, p. 27).

The Accreditation Board for Engineering and Technology (ABET) defined engineering design as follows:

Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs. (ABET, 2011, p. 4)

As teachers seek resources to help them teach engineering design they will encounter many different models of engineering design. The engineering design models often look different (ITEA, 2000, p. 99) and take on many different flowchart configurations, ranging from few steps to many, but the process always contains the fundamental principle of continuity (Gomez, Oakes, & Leone, 2006, p. 130). This continuous process means that a solution to the original problem is not the end; a solution may allow for future modifications in the same product or may open the door to new challenges altogether (Oakes, Leone, & Gunn, 2006, p. 352).

Teachers endeavoring to teach engineering design should understand the difference between analysis and design because it is a distinction that many students struggle with (Horenstein, 2010, p. 28). Analysis is closely related to design. It uses mathematics to find a precise and correct answer (Gomez et al., 2006, p. 18). Alternately, design is searching for the *best* solution among the possible solutions. In design, multiple solutions exist because design is multiobjective in nature. Finding the best solution requires the designer to identify which objectives are most important (Stephan, Bowman, Park, Sill, & Ohland, 2010, p. 43) and historical examples show that arriving at the best solution often requires multiple shifts in approach tactics in order to identify the best solution (Bartholomew, 2014, pp. 138-139). Many factors are in play as a best solution weighs factors like cost, accuracy, robustness, safety, feasibility, functionality, quality, ergonomics, appearance, environmental considerations, and economics (Gomez et al.,

2006, p. 131-133; Horenstein, 2010, p. 28).

An example of the difference between analysis and design can be seen in the example of a lyle gun. A lyle gun, used in the late 19th century until the mid-1950s, was a cannon that shot projectiles attached to a rope out to boats in distress as a saving measure.

> Determining the x-y trajectory of its launched, tethered projectile—a critical part of the effort—is an analysis problem.... In contrast to the problem of analyzing the projectile's trajectory, determining *how to build* the buoy catapult system most certainly involves design. Such a system can be built in more than one way, and the designer must decide which method is best. Should the carriage be made from wood or metal? The former will be lighter and easier for the rescue brigade to bring to the closest shore, but the latter will be stronger and less likely to fail. Wood can rot, but steel can rust. Should the support for the breeching cable be H-shaped or X-shaped? How large should they [sic] buoy be? Should the cannon rest on wheels or skids? Answering these questions requires experimentation, analysis, testing, evaluation, revision—and of course, creativity—all of which are elements of the design process. (Horenstein, 2010, pp. 29-31)

Solutions are just as unique as their corresponding design challenges and each solution will cater better to specific objectives and aspects of a design need. Being able to address the most important categories for each individual design is a function of being proficient at the engineering design process.

A survey of undergraduate engineering students was done that showed the evolution of students' conceptions about the engineering design process as their understanding of the process matured. The study asked 89 freshmen engineering undergraduates about their conceptions of engineering design and then asked the same 89 students the same question again when they were seniors. On both occasions they were presented with 23 aspects of the engineering design process and then asked to pick the six most important elements of engineering design. Their responses clearly indicate that experts place more importance on "understanding the problem" than novices do—in fact,

"understanding the problem" was the most often selected choice, by far, among the graduating seniors; it was selected by nearly 80% of outgoing seniors, where no other element of the engineering design process reached a selection rate of even 50%. A textbook designed to teach high school engineering fundamentals agrees that "defining the problem can be the most important step in the design process. Once the real problem has been identified, the problem is well on its way to being solved" (Brown et al., 2014, p. 24).

Key Steps of Engineering Design

There is no single engineering design model that is agreed upon. There is no consensus among professionals about what the engineering design model looks like. They do, however, agree on several steps that are always involved.

1. Identifying the problem
2. Generating ideas
3. Requirements of the problem are identified
4. Models or prototypes are built and tested
5. Solution must be refined

Summary

In summary, science has had many influential happenings and publications. When Sputnik was launched, the U.S. responded by altering its science education. Later, *A Nation at Risk* showed that our educational system had regressed to pre-sputnik levels

and suggested that the U.S. should not be content with its then-current system. A few

years later, *Science for All Americans* was published, and followed closely by

Benchmarks for Science Literacy. Both were publications which greatly influenced

science classrooms all over the country and soon influenced the *National Science*

Education Standards (published by the NRC in 1996). Those standards were the most

current science standards until the publication of the NGSS, which were heavily

influenced by the *Framework for K-12 Science Education.*

The NGSS play a role in the nation's larger STEM push that is occurring

throughout education. STEM integration is achieved in part by the inclusion of

engineering design into NGSS. Engineering design is, however, new to the discipline of

science and because of that, many people have expressed opinions that science teachers

are not ready to teach engineering design. With no consensus on a specific model of

engineering design, it is important to note that there are still consensus elements of the

engineering design process, such as the iterative refinement process.

In spite of the speculated lack of science teacher preparation, the inclusion of

engineering design into science is in line with recommendations from the NAE. As of the

writing of this report no studies have definitively probed science teachers' feelings of

preparedness regarding the basic aspects of engineering design and goals of engineering.

Conclusion

It is the recommendation of this study that further research be conducted into

whether or not science teachers feel prepared to teach the engineering design content, and

what help they may require to feel more prepared. Research has shown a teacher's feeling of preparedness to be extremely important because "variation in teachers' feelings of preparedness to teach...is very likely to affect their students' opportunities to learn. The potential for inequity is great" (PROM/SE, 2006, pp. 11-12). It is important to establish how prepared public secondary science teachers feel about teaching engineering design.

The results will not only benefit the current teachers, but also school administrators as they support professional development and are better informed in science education. Likewise, it will benefit teacher educators and persons involved with the Utah State Office of Education and state STEM action center by showing what preparation needs to be provided to teachers in order to give students the highest rate of success.

CHAPTER III

METHODS

This study has endeavored to be a study that is replicable and applicable. To this end, the methodology is reported in this section. The research problem and objectives, together with H_0 (null) and H_1 (alternative) hypotheses, will be restated. The type of design will be identified as well the format of delivery. The vehicle for dissemination, through the help of the Utah State Office of Education, will be discussed and number of persons in the target population is given. The software and statistical methods used for interpreting the raw data will be identified.

Research Problem and Questions

This study was conducted to answer the following questions:

1. Do secondary school science educators in Utah feel prepared to teach engineering design as measured through practices identified in the *Framework for K-12 Science Education* (NRC, 2012)?

2. Do science teachers recognize the difference between the aims of science and the aim of the engineering design process?

3. Do science educators exhibit any inclination toward the delivery method of technology and engineering education in teaching engineering design?

For the first research question in this study, the following hypotheses were stated.

H_0: 80% of public secondary education science teachers in Utah feel either prepared or very prepared to teach engineering design in their science classrooms.

H$_1$: Less than 80% of public secondary education science in Utah feel either prepared or very prepared to teach engineering design in their science classrooms.

Research Design

This was a quantitative descriptive survey that was delivered electronically via e-mail that included an explanation of the survey and link to the actual survey where directions were given. The purpose of this descriptive survey is consistent with similar designs which capture a snapshot of the landscape as it exists at one point in time. It does not show cause and effect, nor does it attempt to alter any component of the existing landscape (Leedy & Ormrod, 2012, p. 184). In this case, the study sought to understand the current feelings of preparation to teach engineering design among those in the public secondary science Utah educator community.

Data Collection

The survey instrument was approved by Utah State University's Institutional Review Board (IRB) and afterwards the survey was sent out to Utah science teachers. The state science specialist for the state of Utah, Sarah Young, agreed to distribute the survey to all of the science teachers for whom she had contact information. There was no database available to the public which contained the contact information for all of the public school science teachers because it would be a violation of privacy rights. Not even Sarah Young had access to any such complete database, which would contain all 1,517 public secondary science teachers in the state (S. Young, personal communication, April

15, 2014). However, there was a database that had contact information for some Utah science educators, which was provided by those educators of their own choice. This opt-in database had roughly 650 Utah science educators as of the end of 2013. Ms. Young offered to distribute the electronic survey to all members of that database. This was the most effective way to distribute the survey.

Instrumentation

The survey (see Appendix A) that was used was developed through discussions between the author and his committee members, Drs. Edward Reeve, Gary Stewardson, and Kim Lott. The former Box Elder school district science coordinator, Emma Smith, was also consulted in the instrument's preliminary development. The survey was submitted for feedback to all members of the committee.

The survey was then piloted by science teachers at a Utah public secondary school. They were asked to look at the survey to determine if statements were confusing or difficult to understand. The response from this focus group was that the survey was clear and made sense.

Persons completing the survey were not stopped from progressing through the survey when questions were left blank, and incomplete data did not stop a person from submitting their survey. Blank answers were omitted from analysis. The answers that were filled in and submitted were used and analyzed, regardless of the completion status of the survey.

A demographic profile of the survey respondents was collected at the end of the

survey. The only demographic information that was collected was regarding the person's science teacher status, teaching endorsements, teaching experience, and current teaching assignments (see Appendix A). No information was collected that contains names, ages, school or district affiliations (or any geographical identifier), income levels, ethnicities, or gender identities. Outside of the specified demographic questions, questions were asked regarding engineering design. The data that these questions produced was collected through many questions involving a Likert scale, where each response was given a value of 1 through 5, numbered from left to right where 1 was equated to strongly disagree and 5 equated to strongly agree. This produced ordinal data that was analyzed using frequency counts, percentages, and where applicable: mode, median, and mean. This is consistent with common treatments of descriptive survey data (Leedy & Ormrod, 2012, p. 189). Standard deviation and variance were also computed and given to provide context for all of the other calculated indicators previously stated. H_0 was tested using the chi square test.

<div align="center">**Conditions of Testing**</div>

The survey was administered electronically and therefore the environmental conditions surrounding the participant were not controlled, nor predictably consistent between the various participants. In the spring of 2014, each participant received the same email with the same explanation of the questionnaire and the same request for help (see Appendix B). There was a link to the survey included in the e-mail, which was provided in a format that provided a uniform resource locator (URL) that showed the web

address of the survey. The URL was hyperlinked to the survey.

It is estimated that as participants filled out the survey, there were many uncontrollable environmental factors that may have impaired the integrity of the data (i.e., background noise, interruptions, etc.). This will have to be recognized and accepted because short of paying all science teachers to come to a controlled environment, it could not be corrected. No time limit was set on the participant's allotted completion time once they opened the survey. The survey was open for participants to fill out for a period of two weeks. The first e-mail was sent on the first day that the survey was open. The second e-mail (a reminder) was sent on the eighth day that the survey was open.

The e-mail asked for participation in the survey and informed the prospective participants that no identifying information would be collected and the survey would therefore be kept entirely anonymous. The intent of this was to encourage each participant to answer honestly. The study was explained to the prospective participants as one having a purpose in finding current needs and perceptions relating to teaching engineering design.

Certainly science educators would feel restricted in giving free answers if identifying factors and information were collected. To allow the participants of this study to be forthcoming on their answers, all responses were given anonymously and no information was collected that could lead to a respondent's identification.

Treatments

All participants received the same survey that asked the questions in the same

order. A copy of the survey is in Appendix A.

Data Analysis

The data were collected through Qualtrics via Utah State University's access and was analyzed by SPSS. The survey, as mentioned above, was distributed to approximately 650 state science teachers, and the results have been used to make inferences about a population of approximately 1,500 people (S. Young, personal communication, April 15, 2014).

Many questions were asked in the survey, with presented response options ranging from "not very prepared" to "very prepared." Each response level was defined in order to afford all respondents a consistent view of what the varying response levels meant.

An individual chi square test was performed on each response item to evaluate H_0 for all aspects of the engineering design process. The chi-square test used the following formula, where frequency of item selected is represented by the variable f. The variables f_o and f_e was respectively represent observed and expected frequencies: $\chi^2 = \sum((f_o-f_e)^2/f_e)$

The critical value that was used to evaluate H_0 depended on the degrees of freedom (which are dictated by the number of respondents). Thus, the critical value used in the statistical evaluation varied by question and was dependent on the number of responses each question received.

The questions for the survey have been developed with statements directly from the *Framework for K-12 Science Education* and NGSS. The third chapter in the

Framework for K-12 Science Education is devoted to expounding scientific and engineering practices. Eight practices that are considered to be "essential elements of K-12 science and engineering curriculum" (NRC, 2012, p. 49) are identified by these publications. These eight practices are:

1. Asking questions (for science) and defining problems (for engineering)

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 (for science) and designing solutions (for engineering)

7. Engaging in argument from evidence

8. Obtaining, evaluating, and communicating information

These eight practices are used in both science and engineering, but the practices are often manifested differently between science and engineering as identified in parenthetical information above. The common manifestations of each of the eight practices are presented for comparison in the above-referenced chapter of the *Framework for K-12 Science Education* (NRC, 2012). Most of the questions on the survey were taken directly from the differences highlighted in those *Framework for K-12 Science Education* comparisons. A few other questions (four) were taken directly from the same chapter of the *Framework for K-12 Science Education.* The NGSS's engineering design standards make explicit reference to these same eight practices identified in the *Framework for K-*

12 Science Education and even note that much of the NGSS engineering design standard is taken "verbatim" (NGSS, 2013d, p. 1) from the *Framework for K-12 Science Education*. Last, four more survey questions were created by Dr. Stewardson and the author of this report to reflect the difference in delivery approaches taken by Technology and Engineering Education and recommended by NGSS. Those questions were informed by, and used language from the STL and the NGSS.

CHAPTER IV

FINDINGS

The primary purpose of this study was to determine the feelings of preparedness of public secondary education science teachers across the state of Utah to teach the principle of engineering design in their science classrooms. To measure those feelings of preparedness, an instrument was developed using the language of the *Framework for K-12 Science Education* (NRC, 2012) and distributed to the entire target population whose contact information was given voluntarily to the Utah State Office of Education.

The survey was distributed through Sarah Young, the science specialist at Utah's State Office of Education. The survey was distributed to approximately 650 secondary science teachers; 80 respondents completed the entire survey. This means that they clicked through until the end of the survey but does not mean that every question was answered by all 80 (no question ever received fewer than 73 responses). Another 18 survey participants exited the survey before it was fully completed for a total of 98 full or partial surveys filled out. The response rate was 15%. With nearly 100 respondents and about 1,500 secondary education public science teachers in the state of Utah, approximately 1 out of every 15 teachers in the targeted population responded.

Of the teachers who responded, four brief questions were asked to ascertain the demographics of those answering the questions. It was found that 92% of those filling out the survey were currently teaching one or more science classes. In addition, 47% were currently teaching integrated science—making it the most often selected class subject taught by survey participants. The next most frequently taught class subjects were

indicated to be biology (27%), earth science (20%), and physics (20%). The most frequently held current teaching endorsements among respondents were middle level science (53%), biological science (40%), physical science (34%), and earth science (32%). The average number of years taught among the survey respondents was 11.93 years with a standard deviation of 9.31.

The first research question was to determine if the target population of teachers felt prepared to teach engineering design. The 11 statements were taken from a chapter of the *Framework for K-12 Science Education* (NRC, 2012) dedicated to differentiating between the practices of science and engineering. While both disciplines use many of the same principles, they each use those same principles in different ways. The *Framework for K-12 Science Education* compares side by side how each principle is manifested in science with how the principle is manifested in engineering. It is from this section of side by side comparisons that all of the statements to this central survey question came. The *Framework for K-12 Science Education* listed and compared the most essential eight principles. For purposes of clarity in the instrument, a few of the statements were broken into two or more statements, which resulted in 11, not 8, statements to be evaluated by the teachers. A reference guide of when to select each level of preparedness was provided to more closely standardize the scale in the eyes of the participants. Each statement is given in Table 1 and is accompanied by its corresponding mean, standard deviation (σ), median, mode, and variance (σ^2).

In Chapter III, it was indicated that the null hypothesis would be evaluated through the use of a chi-square test. That test was to be run for each statement to

Table 1

Mean, Median, Mode, and Variance of Feelings of Teacher Preparedness

Statement number	Evaluated statement	*M* (*SD*)	95% CI	Median	Mode	σ^2
1	I feel confident in attending to a broad range of considerations in criteria and constraints for problems of social and global significance.	3.33$_{abc}$ (1.04)	[3.09, 3.56]	3	3	1.08
2	I feel confident beginning with a problem, need, or desire and asking questions to define the engineering problem.	3.66$_{bcd}$ (1.02)	[3.44, 3.89]	4	4	1.04
3	I feel confident in determining criteria for a successful solution.	3.58$_{bcd}$ (1.16)	[3.32, 3.83]	4	4	1.34
4	I feel confident in identifying constraints.	3.51$_{bcd}$ (1.17)	[3.25, 3.77]	4	4	1.37
5	I feel confident in making use of models and simulations to analyze existing systems so as to see where flaws might occur or to test possible solutions to a new problem.	3.35$_{abc}$ (1.19)	[3.08, 3.62]	3.5	4	1.42
6	I feel confident to use investigation to gain data essential for specifying design criteria or parameters and to test designs.	3.60$_{bcd}$ (1.23)	[3.33, 3.87]	4	4	1.51
7	I feel confident in analyzing data collected in the tests of designs and investigations.	3.73$_{cd}$ (1.01)	[3.50, 3.95]	4	4	1.01
8	I feel confident in using mathematical and computational representations of established relationships and principles.	3.09$_{ab}$ (1.32)	[2.79, 3.38]	3	4	1.75
9	I feel confident in developing solutions which result from a process of balancing competing criteria of desired functions, technological feasibility, cost, safety, aesthetics, and compliance with legal requirements.	2.89$_{a}$ (1.27)	[2.60, 3.17]	3	3	1.62
10	I feel confident in using systematic methods to compare alternatives, formulate evidence based on test data, make arguments from evidence to defend their conclusions, evaluate critically the ideas of others, and revise designs in order to achieve the best solution to the problem at hand.	3.24$_{abc}$ (1.18)	[2.97, 3.50]	3	4	1.40
11	I feel confident in expressing ideas, orally and in writing, with the use of tables, graphs, drawings, or models and by engaging in extended discussions with peers	3.94$_{d}$ (1.00)	[3.72, 4.16]	4	4	1.00

Note. N = 80. Means sharing a common subscript are not statistically different at α = .05.

determine which, if any, of the statements met the expectations of the null hypothesis.

The chi-square test looks at expected frequencies for each statement and compares it against the observed frequencies. The chi square test results and the probability level of making an incorrect conclusion are given in Table 2 for each of the 11 statements listed in Table 1. A confidence interval of 95% was used.

The mean values for each statement were compared in order to find the statements to which the target population indicated feeling the least prepared to teach. In order to compare multiple mean values at the same time, a one-way analysis of variance (ANOVA) was executed. The ANOVA produced an F value of 5.57; $F(73.51, 1147.88) = 5.57, p < .01$.

All of the discussion up until this point in this chapter has focused on the first question of the instrument. That question aimed to quantify the average feelings of preparedness to teach engineering design in a science classroom. Two other questions in

Table 2

Chi-Square Test Results

Statement number	Chi square (χ^2)	Probability
1	92.64	< .001
2	37.65	< .001
3	25.78	< .001
4	36.90	< .001
5	96.44	< .001
6	18.23	.001
7	33.32	< .001
8	70.90	< .001
9	102.77	< .001
10	69.4	< .001
11	9.14	.058

the instrument also recorded responses on a Likert scale. The first of those two questions

attempted to gauge how well teachers understood the aim of engineering design. To

contrast, questions about the aim of science were also included. The language of these

questions was taken from the *Framework for K-12 Science Education* (NRC, 2012). For

each statement about the aim of science or engineering, the participants were asked to

select their opinion of the statement and given the option to select any of the following

responses: strongly disagree (1), disagree (2), neutral (3), agree (4), strongly agree (5).

Table 3 presents the outcomes associated with these questions.

To determine if the means are statistically different from each other, an ANOVA

was executed with the data from the responses. The ANOVA produced an *F* value of

42.34; $F(3, 349) = 42.34$, $p < .001$. Differentiations, revealed through post-hoc test results

(using Tukey's method), are also noted in Table 3.

The last question that was asked with a Likert scale pertained to various teaching

Table 3

Mean, Median, and Mode of Teacher Agreement with Discipline Aims

Statement number	Evaluated statement	*M* (*SD*)	95% CI	Median	Mode
12	The aim of science is to find a single coherent and comprehensive theory for a range of related phenomena.	2.93$_a$ (1.10)	[2.70, 3.16]	3	2
13	In Engineering, there is never just one "correct" solution to a design challenge.	4.47$_c$ (0.62)	[4.34, 4.60]	5	5
14	For science, developing an explanation constitutes success in and of itself.	3.67$_b$ (1.01)	[3.46, 3.89]	4	4
15	For engineering, success is measured by the extent to which a human need or want has been addressed.	3.79$_b$ (0.86)	[3.61, 3.83]	4	4

Note. $n = 89$. Means sharing a common subscript are not statistically different at $\alpha = .05$.

methods that could be employed to teach engineering design. Two of the four statements

(statements 16 and 18) were constructed by consulting the language found in the *NGSS*

engineering design standards. The other two (statements 17 and 19), were constructed by

consulting the engineering design standards as published in the *Standards for*

Technological Literacy (ITEA; 2000). The STL was selected as a contrast because it

represents the most nationally accepted set of standards used by technology and

engineering education teachers; technology and engineering education teachers are those

who currently teach engineering design in the U.S. public education system.

In this question about teaching methods, participants were asked to indicate to

what extent they agreed or disagreed with the given method of teaching engineering

design in a science classroom by selecting one of the following responses: strongly

disagree (1), disagree (2), neutral (3), agree (4), strongly agree (5). The responses are

shown in Table 4. An ANOVA was computed and produced an *F* value of 1.56; $F(3,$

$348) = 1.561, p = .199$.

Table 4

Mean, Median, and Mode of Teacher Agreement with Varied Delivery Methods

Statement number	Evaluated statement	Mean	*SD*	Median	Mode
16	Evaluate an engineering design solution through mathematical and scientific principles.	4.06	.667	4	4
17	Build a product or system to test a solution of an engineering design.	4.24	.661	4	4
18	Use mathematical and computational modeling to predict the effects of a plausible design solution.	4.09	.637	4	4
19	Test and evaluate an engineering design solution through the construction of a prototype.	4.20	.659	4	4

At the end of the survey, all participants were asked if they felt that they would benefit from professional development that taught them how to use the engineering design process in their science classroom. 97% of participants indicated that yes, they would benefit from professional development. Participants were then presented with seven possible types of professional development and asked which types they felt would benefit them. Each participant could select as many as they felt would benefit, with no limit to the number of selections. The percent of participants who selected each type is given in Table 5.

The question regarding feelings of teacher preparedness resulted in means that lie almost entirely between somewhat prepared (3) and prepared (4). Also, a virtual unanimity (97%) indicated that professional development about engineering design would benefit them. The participants of the study also indicated a strong agreement (4.47 mean) with the fact that engineering never has just one "correct" solution. Lastly, agreement with each presented method of teaching engineering design received a mean score between "agree" (4) and "strongly agree" (5).

Table 5

Professional Development That Teachers Believe Would Be of Benefit

Type of professional development	% who would benefit
Content knowledge about the Engineering Design Process.	72
Instruction on the use of engineering equipment and technology in the classroom.	81
Lesson plan ideas.	76
Training on Engineering Design assessment.	67
Instruction on finding appropriate materials.	67
Ready access to one or more expert teachers in engineering design.	62
Networking and collaboration with other science teachers.	76

CHAPTER V

DISCUSSION, CONCLUSIONS, RECOMMENDATIONS

With the results of the study given in the preceding chapter, this chapter will focus on making sense of what the data analysis provided in Chapter IV. Statistical differences will be highlighted and discussed, and important non-statistical differences will also receive attention. This chapter will discuss the demographic information that was collected and will provide a discussion on the research questions, conclusion to the study as well as recommendations for future action.

Demographics

The teachers who responded showed a level of veteran expertise with an average of almost 12 years teaching experience per respondent. The standard deviation of more than 9 shows a wide range of teacher experience. Further, all of the science teaching endorsements offered by the state of Utah were well represented by the survey participants. Although there was a low response rate, it can be concluded that between the indicated years of teaching experience and the indicated subject expertise of all participants, it appears that a heterogeneous portion of the teacher spectrum was successfully captured. These inferences and findings should be valid for discussion about the public secondary education science teachers across the state of Utah.

Discussion

The research questions asked in this study were as follows.

1. Do secondary school science educators in Utah feel prepared to teach engineering design as measured through practices identified in the *Framework for K-12 Science Education* (NRC, 2012)?

2. Do science teachers recognize the difference between the aims of science and the aim of the engineering design process?

3. Do science educators exhibit any inclination toward the delivery method of technology and engineering education in teaching engineering design?

For the first research question, this study found that secondary education science teachers in the State of Utah do not feel as prepared to teach the engineering design process in their science classrooms as they would like to be. The null hypothesis stated that 80% of Utah's public secondary education science teachers would feel either prepared or very prepared to teach engineering design in their science classroom. That null hypothesis is rejected based on the chi square findings given in Chapter IV.

For the second research question, this study found that secondary education science teachers in the State of Utah recognized the difference between the aim of science and the aim of engineering. However, they did not feel confident teaching the aspects of engineering that they most easily recognize.

The third question of this study was to determine if secondary education science teachers exhibited any inclination toward the delivery method of technology and engineering education in teaching engineering design. They do. While preference for a delivery method was not asked, science teachers readily agreed with the delivery method of technology and engineering education in a science classroom.

Feelings of Preparedness

Research question number one attempted to gauge feelings of teacher preparedness to teach engineering design by asking them to rate their feelings of preparedness on various statements. The mean response for each statement ranged between "somewhat prepared" to "prepared." An explanation of each statement was provided on all surveys to help guide the respondents and standardize their paradigms. By these explanations it can be said that all responses ranged from "I know about it, but would need to brush up on it," to "I know enough to teach it, but have never prepared a lesson with it." These responses show that science teachers, in general, simply lack experience and possibly exposure to engineering design.

Of all of the statements evaluated, seven statements are grouped together in the middle of the response mean ordering. Table 1 showed the groupings revealed through post-hoc tests. These seven grouped statements show some trends, but ultimately the values they produced are not statistically different from each other. With seven in the middle of the ordering, and eleven responses altogether, four responses were left. These other four statements, however, appear to be statistically different enough to allow for further exploration, discussion and recommendations. Of the four, two statements clearly identified the areas with the lowest feelings of preparedness. The two others clearly identified the areas with the highest feelings of preparedness. Table 1 also showed statements 9 and 8 as the statements that elicited the lowest feelings of preparedness. Both statements are given below.

9. I feel confident in developing solutions which result from a process of balancing competing criteria of desired functions, technological feasibility,

cost, safety, aesthetics, and compliance with legal requirements.

8. I feel confident in using mathematical and computational representations of established relationships and principles.

It can be inferred, then, that the target population felt only somewhat prepared to utilize many mathematical calculations in the design process. This could be due to the high proportion of science areas that are not mathematically based and, therefore, leave science teachers out of mathematical practice. The area most in need of a brush-up is related to a teacher's ability to develop a solution that takes into account several competing criteria. Much of science is devoted to finding correct explanations. This perceived lack of preparation could be tied to the differing aims of science and engineering. Science aims to explain why phenomena occur and being able to find that explanation constitutes success. By contrast, engineering deals in a world of trade-offs, not complete harmony, and seeks the best way to address a human need or want by consulting competing criteria (NRC, 2012, p. 48).

Interestingly, when asked to agree or disagree with the different aims of engineering and science, the participants strongly agreed with the statement that in engineering there never is one single "correct" design solution. This could indicate that the Utah science teachers' lowest feelings of preparedness is in regard to the one thing that they most strongly identify as "engineering." The teachers very clearly understand that engineering does not seek a single "correct" design solution, but that is the very thing that they feel least prepared to teach.

Table 1 also showed the two areas with the strongest feelings of preparedness, which are statements 11 and 7.

11. I feel confident in expressing ideas, orally and in writing, with the use of tables, graphs, drawings, or models and by engaging in extended discussions with peers.

7. I feel confident in analyzing data collected in the tests of designs and investigations.

These statements and their outcomes would suggest that of topics relating to engineering design, science teachers were the most familiar and comfortable with topics relating to charts, graphs, and analysis. Because of the contrast between lower feelings of preparedness with "mathematical and computational representations" and higher feelings of preparedness with "analysis," it seems reasonable to assume that science teachers are comfortable with analysis that is not overtly mathematical. They indicated that they feel comfortable communicating with graphs, charts, drawings and the most comfortable analyses might fall in that realm as well.

Another intriguing result came out of the data analysis. It seems that one of the most succinct indicators of feelings of preparedness is a question that was not designed to reveal feelings of preparedness. The serendipitous question is that of professional development. Teachers were asked if they felt they would benefit from professional development regarding engineering design in a science classroom. The staggeringly unified response of 97% was a virtually unanimous "yes." This question, more than any other, showed that the teachers in the state of Utah would like to feel more prepared to teach engineering design than they currently do.

The question was then asked which type of professional development would be beneficial (seven options were provided). Respondents were allowed to select as many of the seven provided options as they felt would truly benefit them. None of the seven

provided types of professional development was selected fewer than 60% of the time. From this it is clear that a start in professional development is needed, and that start can practically be from any perspective. They would benefit from almost any professional development.

Hypothesis Decision

The null hypothesis, given in Chapters I and III, stated that at least 80% of the public secondary science educators in Utah would indicate being either prepared or very well prepared to teach engineering design. In this research, a chi-square test was run for each statement to determine which, if any, of the statements met the expectations of H_0. Statement 11 was the only statement that met those expectations.

The decision regarding the hypothesis was to reject the H_0 for statements 1-10 and fail to reject H_0 for statement 11. As noted above in the discussion of the ANOVA results, statement 11 was clearly the statement to which the participants indicated being the most prepared. Science teachers did feel prepared to express their ideas orally and through graphs. For all other statements it can be concluded that the teachers did not feel prepared, but somewhat prepared.

Methods of Teaching Engineering Design

The study participants were asked to indicate which methods they agreed with or disagreed with for presenting engineering design in a science classroom. The different statements corresponded to either descriptions derived from the science's NGSS or technology's STL. Somewhat unexpectedly, the teachers agreed with both methods of

presentation inside of a science classroom. Statements derived from both the NGSS and STL were received very favorably and no statistical difference was found between them. This suggests that science teachers might be open to teaching engineering design in a way that is found most predominantly in a technology and engineering education classroom.

The question did not ask for a preference among teaching styles, only to what extent a teacher agreed with the method for a science classroom. It is possible that science teachers agree with technology and engineering education methods but actually prefer methods that align more closely with NGSS. A bias in favor of technology and engineering education methods might also be an unknowingly ingrained bias gained through association with technology and engineering teachers.

Conclusions

In the state of Utah, science teachers knew what engineering and engineering design was, and they felt somewhat prepared to teach it, but they would like inservice to help them feel more prepared. It should be noted that with only a 15% total response rate, the true responses of the entire target population could vary somewhat from the findings of this study.

As STEM education is furthered, more and more silos will need to integrate. The inclusion of engineering design into science is one example of the STEM disciplines breaking down those silos. This show of integration makes it easy to understand why the inclusion of engineering design into science has generated excited around the U.S. As Utah seeks to strengthen its STEM education, it makes sense to push for the inclusion of

engineering design into science. Further, and because technology and engineering education currently teaches engineering design, it could lead to a more full inclusion of technology with the other three STEM subjects. This would strengthen the overall STEM education and help prepare an even broader spectrum of students.

However, science teachers need support to feel prepared enough to deliver engineering design content. They need better support and instruction at all levels ranging from professional development, to teacher education, and even to the state standards. When engineering design is included into a state's science standards, it reverberates around the state and brings support from many corners. It makes sense for Utah to pursue a stronger STEM education; Utah is already trying to pursue a stronger STEM education. Supporting this inclusion of engineering design into science will be an important step forward.

Recommendations

The recommendations of this report apply to school administrators as they search for topics of professional development to support, teacher educators as they prepare future science teachers, state officials as they look to integrate all STEM subjects, and researchers who are looking further into the inclusion of engineering design in science. The following recommendations are given and justified.

1. Prepare, deliver, and encourage attendance to professional development that focuses on (a) developing solutions in the midst of competing criteria and (b) running mathematical and computational analyses.

2. Include content of and exposure to engineering design in preservice teacher programs.

3. Explicitly include engineering design into state science standards.

4. Conduct further research into the preferred methods of teaching engineering design in a science classroom.

5. Reach out to technology and engineering educators as a potential resource for science educators.

This study clearly showed that science education teachers in the State of Utah would benefit from professional development. They made that very clear from their 97% affirmation during the study. The feelings of preparation are somewhat low, and yet, to break down the barriers between STEM subjects, it would be best for everyone if those feelings of preparation were raised. Teachers would not only feel more comfortable, they would likely be more apt to deliver competent and engaging instruction. Students would have an easier time engaging with the material and might take a longer look at a career in engineering, which would benefit our state and our nation. One of the most effective ways to encourage the inclusion of engineering design is through the state standards. As the state science standards are revisited, it would be beneficial to include engineering design. Inclusion into the state standards alone would encourage mass professional development and alterations to preservice curriculum. All of these changes together would contribute to a more integrated and informed STEM education throughout the state, which is good for the state's economy and its participants.

The technology and engineering education community should be regarded as a

tremendous resource for science during this process. Technology and engineering education does not have the critical mass necessary to deliver instruction on engineering design to all students, but it has experience teaching the subject. Since science teachers have not shown a disagreement with teaching engineering design from a technology and engineering education method, it stands to reason to involve technology and engineering education teachers as a resource for science teachers. Science teachers would seem to be in favor of this, as the most requested form of professional development was training with engineering equipment and technology (81%), followed closely by a desire for networking/collaboration (76%) and lesson plan ideas (76%).

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APPENDICES

Appendix A

Survey

qualtrics

UtahState University
Department of Applied Sciences,
Technology, & Education
2300 Old Main Hill
Logan UT 84322
Telephone: (435) 797-2230

Full AAHRPP Accreditation

Letter of Information

A Survey of Utah's Public Secondary Education Science Teachers to Determine Their Feelings of Preparedness to Teach Engineering Design

Introduction/ Purpose Dr. Edward Reeve and graduate student Tyler Ames in the School of Applied Sciences, Technology, and Education at Utah State University are conducting a research study to find out more about Utah science teachers' feelings of preparedness to teach the principle of engineering design as advocated in the Next Generation Science Standards. You have been asked to take part because you are a science teacher in Utah. There will be approximately 150 total participants in this research

Procedures If you agree to be in this research study, you will be asked to answer several questions regarding your feeling of preparedness to teach various aspects of engineering design. This should take about 5-7 minutes.

Risks There is minimal risk in participating in this research.

Benefits There is no direct benefit to you for participating in this research study. However, your feedback will be used to help inform and shape professional development around the state of Utah for science teachers.

Explanation & offer to answer questions Tyler Ames has explained this research study to you and answered your questions. If you have other questions or research-related problems, you may reach Dr. Edward Reeve at (435) 797-3642

Voluntary nature of participation and right to withdraw without consequence Participation in research is entirely voluntary. You may refuse to participate or withdraw at any time without consequence or loss of benefits.

Confidentiality Research records will be kept confidential, consistent with federal and state regulations. Only the investigator and Tyler Ames will have access to the data which will be kept in a locked file cabinet or on a password protected computer in a locked room. Your internet protocol (IP) address will not be recorded.

IRB Approval Statement The Institutional Review Board for the protection of human participants at Utah State University has approved this research study. If you have any questions or concerns about your rights or a research-related injury and would like to contact someone other than the research team, you may contact the IRB Administrator at (435) 797-0567 or email irb@usu.edu to obtain information or to offer input.

Investigator Statement "I certify that the research study has been explained to the individual, by me or my research staff, and that the individual understands the nature and purpose, the possible risks and benefits associated with taking part in this research study. Any questions that have been raised have been answered."

Edward Reeve
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Qualtrics

The Next Generation Science Standards (NGSS) promote Science and Engineering Practices. For many involved in science education, teaching engineering practices (i.e., knowledge and skills) will be a new area. The purpose of this short survey is to find out about your needs and perceptions related to teaching engineering practices, included to those related to using engineering design in the classroom.

Thank you for completing this short survey. Information obtained in this survey will be used to help develop appropriate professional development opportunities related to the NGSS.

>>

Qualtrics

Please indicate to what extent you agree or disagree with the following statements.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The aim of science is to find a single coherent and comprehensive theory for a range of related phenomena.	○	○	○	○	○
In Engineering, there is never just one "correct" solution to a design challenge.	○	○	○	○	○
For science, developing an explanation constitutes success in and of itself.	○	○	○	○	○
For Engineering, success is measured by the extent to which a human need or want has been addressed.	○	○	○	○	○

The following are all practices used by engineers during the design process. How well prepared do you feel you are to implement the following in your science classroom?

Very well prepared= I have taught it before and feel prepared to teach it again.
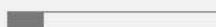**Prepared**= I know enough to teach it, but have never prepared a lesson with it
Somewhat prepared= I know about it, but would need to brush up on it
Not very prepared= I have seen it and know what preparation materials to consult, but I do not know much else about it
Not prepared at all= I have never seen it before.

	Not prepared at all	Not very prepared	Somewhat prepared	Prepared	Very well prepared
I feel confident in attending to a broad range of considerations in criteria and constraints for problems of social and global significance.	○	○	○	○	○
I feel confident beginning with a problem, need, or desire and asking questions to define the engineering problem.	●	●	●	●	●
I feel confident in determining criteria for a successful solution.	○	○	○	○	○
I feel confident in identifying constraints.	●	●	●	●	●
I feel confident in making use of models and simulations to analyze existing systems so as to see where flaws might occur or to test possible solutions to a new problem.	○	○	○	○	○
I feel confident in determining criteria for a successful solution.	○	○	○	○	○
I feel confident in identifying constraints.	●	●	●	●	●
I feel confident in making use of models and simulations to analyze existing systems so as to see where flaws might occur or to test possible solutions to a new problem.	○	○	○	○	○
I feel confident to use investigation to gain data essential for specifying design criteria or parameters and to test designs.	●	●	●	●	●

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Q qualtrics

The following are all practices used by engineers during the design process. How well prepared do you feel you are to implement the following in your science classroom?

Very well prepared = I have taught it before and feel prepared to teach it again.
Prepared = I know enough to teach it, but have never prepared a lesson with it
Somewhat prepared = I know about it, but would need to brush up on it
Not very prepared = I have seen it and know what preparation materials to consult, but I do not know much else about it
Not prepared at all = I have never seen it before.

	Not prepared at all	Not very prepared	Somewhat prepared	Prepared	Very well prepared
I feel confident in analyzing data collected in the tests of designs and investigations.	○	○	○	○	○
I feel confident in using mathematical and computational representations of established relationships and principles.	●	●	●	●	●
I feel confident in developing solutions which result from a process of balancing competing criteria of desired functions, technological feasibility, cost, safety, aesthetics, and compliance with legal requirements.	○	○	○	○	○
I feel confident in using systematic methods to compare alternatives, formulate evidence based on test data, make arguments from evidence to defend their conclusions, evaluate critically the ideas of others, and revise designs in order to achieve the best solution to the problem at hand.	●	●	●	●	●
I feel confident in expressing ideas, orally and in writing, with the use of tables, graphs, drawings, or models and by engaging in extended discussions with peers	○	○	○	○	○

Do you feel you would benefit from professional development that teaches how to use the engineering design process in the science classroom?

○ Yes

○ No

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qualtrics

What types of professional development do you feel would benefit your ability to teach engineering design? (Select all that apply)

☐ Content Knowledge about Engineering Design Process

☐ Instruction on use of engineering equipment and technology in the classroom

☐ Lesson plan ideas

☐ Training on Engineering Design Assessment

☐ Instruction on finding appropriate materials

☐ Ready access to one or more expert teachers in engineering design

☐ Networking and collaboration with other science teachers

Are you currently teaching 1 or more science classes?

○ Yes

○ No

>>

qualtrics

How many years have you been teaching science?

	0	4	7	11	14	18	22	25	29	32	36
Drag the bar to select the number of years of science teaching experience											

What teaching endorsements do you currently hold? (Select all that apply)

- ☐ Physics
- ☐ Chemistry
- ☐ Biological Science
- ☐ Earth Science
- ☐ Physical Science
- ☐ Environmental Science
- ☐ Middle Level Science
- ☐ Technology and Engineering
- ☐ other

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qualtrics

What subjects are you currently teaching? (Select all that apply)

- ☐ Integrated Science
- ☐ Physics
- ☐ Chemistry
- ☐ Biology
- ☐ Anatomy
- ☐ Physiology
- ☐ Forensics
- ☐ Earth Science
- ☐ Astronomy
- ☐ Ecology
- ☐ Physical Science
- ☐ Technology
- ☐ Science course not listed above
- ☐ Other
- ☐ Retired/Not Presently Employed

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qualtrics

We thank you for your time spent taking this survey.
Your response has been recorded.

Appendix B

Accompanying Letter

To our statewide science educator community:

As many in our field are aware, the Next Generation Science Standards (NGSS) promote Science and Engineering Practices. For many involved in science education, teaching engineering practices (i.e., knowledge and skills) will be a new area. Attached is a link to a short survey intended to help find out about your needs and perceptions related to teaching engineering practices, included to those related to using engineering design in the classroom.

 Information obtained in this survey will be used to help inform efforts to support engineering concepts and training for the future.

Please take a moment to help us understand the needs of Utah a little better. The survey should not take more than 5-7 minutes.

Thank you

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