The Nexus between Science Literacy & Technical Literacy: A State by State Analysis of Engineering Content in State Science Standards

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Abstract

This study explores how engineering concepts are represented in secondary science standards across the nation by examining how engineering and technical concepts are infused into these frameworks. Secondary science standards from 49 states plus the District of Columbia were analyzed and ranked based on how many engineering concepts were found. Findings reveal that most state science standards infuse some engineering concepts into their documents under the umbrella of science, technology and society (STS) strands. In only a few expectations have states (e.g. Pennsylvania, Massachusetts, New York, and Vermont) fully integrated engineering concepts into their existing state science curricula. Specific suggestions are offered regarding how scientific and technical literacy can together promote a richer experience for all students, and perhaps promote the consideration of STEM careers.

Introduction

In a rapidly changing technological world there is a fundamental shift in the composition of the workforce America needs to compete in a global market (BHEF, 2002; NSB, 2004; Smalley, 2003; NSF, 2005; Friedman, 2005; NAE, 2005; NAS, 2007). Our nation's well being depends upon how well we educate our children in science, technology, engineering and math (STEM), because our economic and national security is derived from technological creativity and global competition. A 2007 report by the National Academy of Science, *Rising Above the Gathering Storm*, states, "the danger exists that Americans may not know enough about science, technology, or mathematics to contribute significantly to, or fully benefit from, the knowledge-based economy that is already taking shape around us" (NAS, 2007). Because of this ever-increasing technological and interconnected world, educators strive to keep their curriculum timely and relevant to maintain pace with information-age advances. This challenge is perhaps most pressing for the disciplines of science, engineering and technology as these subjects are the forefront of innovation, and are the cornerstones of many modernizing economies. Addressing these disciplines separately may result in unnecessary overlap and disconnected learning opportunities for students. Albeit not a novel endeavor, this union of science, technology and engineering (along with mathematics), commonly referred to as STEM, was proposed in reform documents going back to the 1980s. Unfortunately, it has yet to be routinely employed in K-12 classrooms for students in the United States.

Literature Review

As catalysts at the forefront of science education reform, *Science for All Americans: Project 2061* (AAAS, 1989), *Benchmarks for Scientific Literacy* (AAAS, 1993), and the *National Science Education Standards* (NRC, 1996) have stressed as a primary and fundamental goal for K-12 students to be scientifically literate. A scientifically literate person is defined to be, "one who is aware that science, mathematics and technology are interdependent human enterprises with strengths and limitations. . . ." (AAAS, 1989, p. xvii) The notion that technology and engineering concepts play essential roles toward this goal has been surprisingly inconsequential (Koehler, Faraclas, Sanchez, Latif, & Kazerounian, 2005).

Early reform documents in science education, particularly *Science for All Americans: Project 2061* [SFAA] (AAAS, 1989, p. xiii), recommend a way of "thinking that is essential for all citizens in a world shaped by science and technology." This long-range, multi-phase initiative began in 1985 as an attempt to spring board the nation in its efforts to achieve scientific literacy. It is based on the notion that, "the science-literate person is one who is aware that science, mathematics and technology are interdependent human enterprises with strengths and limitations; understands the key concepts and principles of science; is familiar with the natural world and recognizes both its diversity and unity; and uses scientific knowledge and scientific ways of thinking for individual and social purposes" (p. xvii). As described throughout the document, technology plays an essential role in this objective, and is specifically addressed in the chapter, *The Nature of Technology*, where technology and engineering are discussed as means to promote scientific literacy. In a second and an equally important chapter titled, *The Designed World,* technology and human activity are discussed and reference is made to how these influences have shaped the environment and our lives. This chapter outlines eight basic technological areas that can promote scientific literacy: (1) agriculture, (2) materials, (3) manufacturing, (4) energy sources, (5) energy use, (6) communication, (7) information processing, and (8) health technology. As each section defines a basic technological framework necessary for a person to become scientifically literate, it is important to note that the emphasis to include technology, and implicitly engineering through the topics highlighted, is important and purposeful in this reform document. It is important to note that SFAA (AAAS, 1989) and its companion document, *Benchmarks for Scientific Literacy* (AAAS, 1993), acknowledges that technology does not traditionally have a place in the general curriculum and as such, many students fail to learn about it and fail to develop engineering problem-solving skills as a result.

In response to *Science for All Americans: Project 2061* and *Benchmarks for Scientific Literacy*, a third document, the *National Science Education Standards* [NSES] (NRC, 1996) was written to establish national science educational standards. Although SFAA and Benchmarks provided the seminal work addressing science content standards, the call to create a comprehensive document that addressed multiple aspects of science education was initiated. The development of NSES targets more than science content standards, it also incorporates several other important components necessary for a comprehensive science educational program. The NSES echoes with the assertions expressed in SFAA (1989) and stresses technological and engineering concepts in two of its content standards, *Science and Technology*, and *Science in Personal and Social Perspectives*. In Content Standard E: *Science and Technology,* the intent is to "establish connections between the natural and designed worlds and provide students with opportunities to develop decision-making abilities" (NRC, 1996, p.106).

Similarly, Content Standard F: *Science in Personal and Social Perspectives* addresses the social aspect of science thus encouraging students to build a foundation on which to base decisions that will affect them later in life. This content standard recommends that students understand the impact of how science and technology affect local, national, and global issues and challenges. It includes topics in personal and community health, population growth, natural resources, environmental concerns, and natural and human-induced hazards.

As these reform documents stress the nexus between science and technology for science education, the International Technology Education Association (ITEA) took the next step in addressing standards for technological literacy. The ITEA document, *Standards for Technological Literacy: Content for the Study of Technology* [Technology Content Standards] (ITEA, 2000) defines what a student should know and be able to do in order to be technologically literate. Similar to Benchmarks (AAAS, 1993), this document promotes the notion of technological literacy and sets objectives for students in grades K-12 to achieve this goal. There are 20 standards that specify what every student should know and be able to do in order to be technologically literate. This comprehensive outline is the basis for technology education in most high schools, but rarely transcends into mathematics and science curricula. In many secondary schools, technology has been taught traditionally in technology education classes (formally industrial arts), where the emphasis is on a vocational orientation. It targets students who normally enroll in technology education classes, and introduces basic engineering concepts to these students. Unfortunately, because traditional technology courses most often fall into the realm of technology education, many academic students in upper level science and mathematics classes often fail to take advantage of many of these courses taught. These academic students interested in pursuing science and mathematics in college have not explored these options during their high school careers. As a result of this oversight, many fail to be introduced to engineering concepts and modes of technology that contribute to scientific understanding in their high school careers.

As we entered the 21st Century, a call for new common science standards was initiated in a Carnegie report titled, *The Opportunity Equation*. The lessons learned from research in teaching and learning in science as well as the repeated call for US citizens to be more globally competitive sparked the next wave of science education reform in a document titled, *A Framework for K12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012). Developed by the National Research Council [NRC] in concert with interested parties from the sciences, engineering, education and business, this document recommends three dimensions to follow in K-12 science education: (1) scientific and engineering practices; (2) crosscutting conceptions that unify the study of science and engineering; and (3) core ideas in the four disciplines of science, plus engineering, technology and applications of science. The beauty of this document is that this is the first time engineering has been advocated within the national science standards. The implementation of these new frameworks and the accompanying national science standards (NRC, 2013) are in the final stages of writing and are yet to be adopted by States. Until these new reform documents have been adopted, the focus to include engineering in science curricula will be held to a minimum in the K-12 setting.

Currently, each state in the United States has science education standards that guide their science programs in grades K-12. Many states have adopted Benchmarks (AAAS, 1993) and/or NSES (NRC, 1996) to guide their science programs. Typically schools have compartmentalized their science programs at the secondary level into the traditional science disciplines, e.g. earth/space science, biology, chemistry and physics. As recommended by these current reform documents, the incorporation of technology and engineering into the science curriculum is left up to the individual states, school districts, and most importantly, teachers to foster such activities in their classrooms.

Engineering Frameworks

Engineering programs from across the nation have noted that the number of students pursuing careers in engineering has waned in recent decades, and those students who are interested in engineering are not prepared for the academic rigor once they reach the university. This research was completed in association with an NSF GK-12 engineering project (NSF project-#DGE-0139307), designed to introduce engineering and technology concepts to high school students via the science curriculum. One of the explicit goals of this NSF project was to encourage high school students to, at least, ponder the possibility of a career in engineering by introducing engineering concepts into their science and mathematics classes. One of many challenges encountered in the high school science classrooms was that the curriculum was essentially devoid of any related technological and engineering content. To address the inclusion of engineering topics/concepts into the science curriculum, we first operationally defined *technical literacy* as the "ability of an individual to make informed decisions based upon an evolving understanding of the fundamentals of modern technologies" (Koehler, et al., 2005). As a means to achieve this goal, we proposed and developed the Engineering Education Frameworks (EEF) as a grant funded-activity with the aim of promoting technical literacy for high school students. The essence of EEF was to develop a set of guidelines to promote engineering topics/concepts and engineering design into the existing science and mathematics curricula by the simultaneous teaching of multiple science disciplines and this initiative. The content strands developed for EEF provide the context to teach science and engineering concepts. Brown, Collins & Duguid (1989) argues that traditional methods of teaching, "using didactic education assumes a separation between knowing and doing, treating knowledge as an integral, self-sufficient substance, theoretically independent of the situations in which it is learned and used" (p. 32). Using situational cognition as a theoretical framework, the EEF addresses the contextual learning of both science content and engineering concepts, with the ultimate goal of technical and scientific literacy. In our original conception of EEF, we defined four distinct content strands and a set of engineering tools that can facilitate this endeavor. These content strands were a modification of the basic technological areas set forth in SFAA (in *The Designed World* chapter) and we chose these topics because they are commonly studied areas in the field of engineering. To understand these engineering content strands, students will develop an understanding of many disciplines of science and how these disciplines interact with one another. The engineering tools are defined to be the skill set necessary to understand these engineering content strands. Briefly outlined below (Table I) is a description of the content strands and tools necessary for the integration of the EEF frameworks into existing science curricula.

Engineering Education Frameworks (EEF)	Description	Types of Engineering Content Strands
I. Content Standard	Describes *engineering content areas* that can be taught simultaneously with disciplines of science	• Information and Communication • Sources of Power & Energy • Transportation • Food & Medicine
II. Engineering Tools	Describes *tools* necessary to teach engineering content strands	• Engineering Paradigm* • Science • Mathematics • Social Sciences • Computer Tools

Table I: A Brief Description of the Engineering Education Frameworks (EEF)

**Hierarchical Relationship of the Engineering Design Process.* In science classes, students often problem solve.

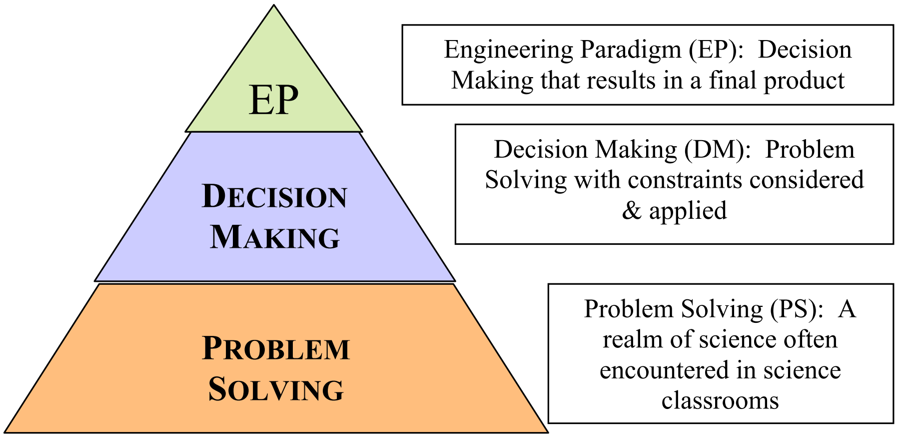

Figure I: The Relationship between Problem Solving, Decision Making and Engineering Paradigm

Engineers approach problem solving in a very different way. They use three different methodologies when tackling a problem; problem solving, decision making, and engineering paradigm (aka engineering design). We have operationally defined a hierarchical relationship between these three methodologies to problem solving in Figure I. Each stage builds upon the complexity of the one below it as seen in the diagram. The engineering paradigm (EP) takes into consideration both problem solving (PS) and decision-making (DM), and oftentimes the end result is a final product.

The engineering paradigm (EP), as described under the category of engineering tools, needs further explanation. This approach is much different than the traditional "problem solving" encountered and practiced in science classrooms as it takes into consideration *constraints* posed on the problem, as well as the *iterative* process that occurs during the decision-making process. As with science, there is no single way to approach an engineering problem and with that in mind, we have defined a template that students can use to mimic the approach used by an engineer while investigating an engineering problem. This EP provides students with a blueprint and outlines the basic steps to consider when attacking an engineering problem. It is not linear, but instead, iterative. We encourage students to use this decision-making process when tackling problems associated within the realm of EEF. A description of the steps of the EP can be found in Figure II (Koehler, et al., 2005).

Research Question

According to the science education documents previously discussed, engineering and technology are advocated within the science curriculum. Since the U.S. state science curricula are based on the science content standards described in these reform documents, the question arises as to how much engineering is actually present in these state science curricula. For this study, we use the EEF in a broader context posing the research question:

To what extent does state science standards incorporate engineering concepts into their secondary science curricula?

Methodology

Each state in the U.S. has defined their own K-12 science standards based on the current science education reform documents (AAAS, 1989, 1993; NRC 1996). Each school district, in turn, develops their science curriculum based on their state science standards. In this study, we examined and analyzed 49 state's current science standards (minus Iowa) plus the District of Columbia for how they incorporate engineering content strands as defined in EEF. By examining how much engineering content is written into the state science standards, we can then infer how much engineering content might potentially be addressed in the high schools within each state. The primary focus of this analysis is on secondary science education (grades 9-12) as this was the targeted age group addressed in the EEF document and the focus of our work in the GK-12 grant. Forty-nine state science standards documents (along with the District of Columbia) were considered in this evaluation. The state science standards documents were found on the website: http://edstandards.org/StSu/Science.html. As noted, not all 50 states were represented in this analysis, as the state of Iowa does not post their science standards online, and thus were not included. Since several states were currently revising their science curriculums, the most current science standard document was analyzed, and when several alternatives were presented, the latest version was considered and analyzed.

Three researchers at the University of Connecticut conducted this analysis. Each researcher's educational background differed, thus bringing a plurality of perspectives to the analysis. Two of the researchers were near completion of a

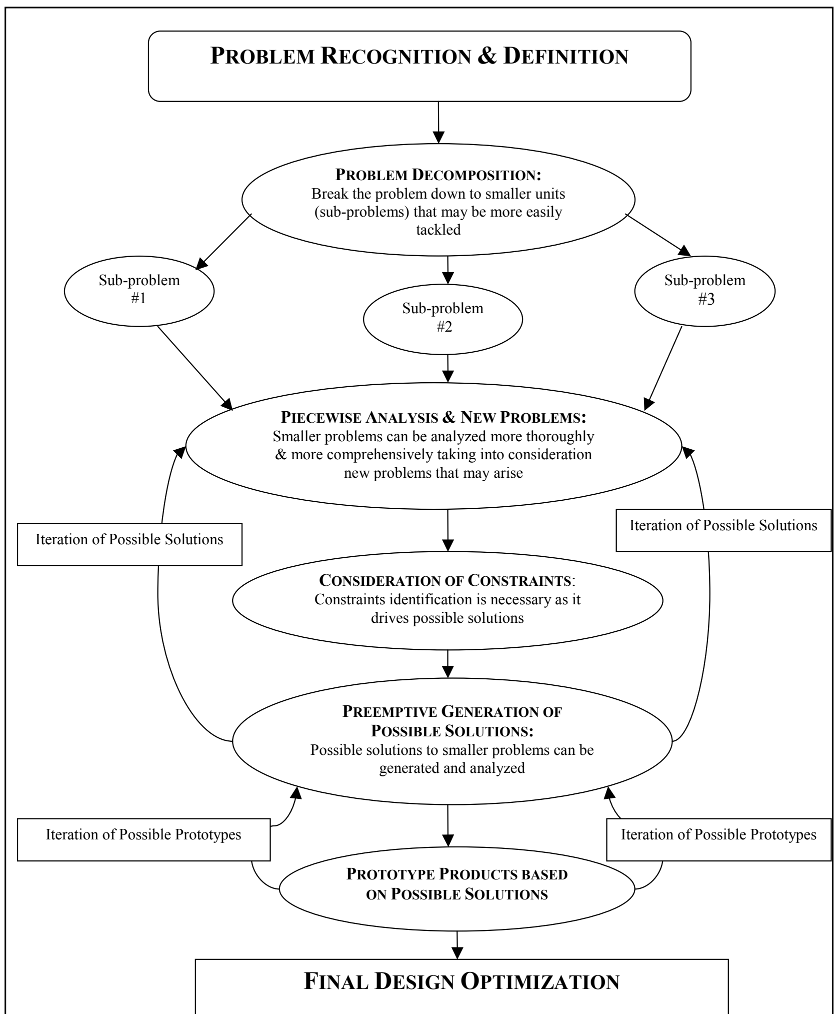

Figure II: Engineering Paradigm

Ph.D. in engineering (in the departments of mechanical and electrical engineering) and the third recently completed a Ph.D. in science education. Each researcher performed an independent and systematic analysis of each state science standards. Twice a week during the fall semester, the three researchers met to discuss six to seven different state science standards. Lively discussion ensued as to the coding of each state then consensus was reached among the researchers as to the appropriate codes assigned. Constant comparative methodology was used to systematically examine and redefine variations on the codes. Triangulation of the data using the "triangulating analysts" approach was a key component in this analysis (Patton, 2003, p. 560). Using this approach, the independent analysis of each researcher was continually compared to the others, thus reducing the inherent bias, and establishing validity and inter-rater reliability. Swanson (2005) suggested this methodology as one technique he used when comparing state science education standards with coding schematics that he conducted when exploring science standards and evolution concepts.

The objective of this analysis was to determine how closely each state's science standards aligned with the EEF document. As the EEF document defines technical literacy, and describes the engineering content strands as means to achieve it for high school students, the codes from EEF were used as the structure and foundation for this analysis. The original EEF standards listed in Table I were the first attempt of defining engineering content strands. For this analysis, additional codes were added to more completely define engineering content areas as suggested by other engineering fellows in the G-K12 project after they reviewed the original EEF document. Their suggestions included these additional content areas: environmental (EN), structural (ST) and manufacturing (MN). As the review of each state's science standards proceeded, two additional codes also emerged and were included in the analysis: systems (SY) and socioeconomics (STS). An important aspect of engineering is ethical and environmental considerations and as the analysis proceeded, it was noted that some states included these aspects within science content areas.

Many states include STS within their science content standards and this code was also included in the analysis. STS in this analysis was interpreted to be any science, technology and society concepts relating to technological advancement and/or hindrance within societal and economic factors. It should also be noted that the codes listed below are in no set order as there is not a hierarchical order of importance for any EEF code; each content strand is equally important in the discipline of engineering. Table II shows the complete set of codes used for this study.

EEF Code Name	EEF Codes	Description of EEF Code
Power & Energy	PE	Technology associated with the acquisition, generation, distribution, and various uses of power and energy.
Information & Communications	IC	Delivers an understanding of how modern communications systems function from the physical hardware to the theory of communication media as well as hands on experience with various devices.
Transportation	TR	From physical infrastructure, to the machines responsible for delivery, the technology behind the transportation of physical products is the cornerstone of modern civilization
Food & Medicine	FM	This covers the technology behind advances in modern medical diagnostic equipment and treatments to the technology responsible for feeding a planet of billions of people.
Environmental	EN	Concepts of environmental practices such as water treatment design, effects on the environment
Structural	ST	Concepts relating to the design of physical structures such as buildings and bridges as well as micro and nano-scaled structures
Manufacturing	MN	Concepts of mass production, product machinability, material selection, product life, metal forming, and cutting technology
Problem Solving	PS	A realm of science used as the foundation of the PS/DM/EP continuum. See Figure 2
Decision Making	DM	The second tier in the PS/DM/EP continuum. It is problem solving plus constraints applied and considered. See Figure 2
Engineering Paradigm	EP	The top tier of the PS/DM/EP continuum. Includes PS as well as DM resulting in a product. See Figure 2
Tools	TL	Engineering tools that apply technology to develop simulations, computer modeling, advanced mathematics, instrumentation, etc.
Systems	SY	Concepts of component need, component interaction, systems interaction, and feedback. The interaction of subcomponents to produce a functional system is a common lens used by all engineering disciplines for understanding, analysis, and design.
Socioeconomic	STS	Science, Technology & Society, concepts relating to technological advancement/hindrance with societal and economic factors. See explanation in results section of this document

Table II: Codes Used for Analyzing Secondary State Science Frameworks

"Typical" *Science* Objective in a Physics curriculum	Science Objective Integrating Engineering Concepts
By the end of this lesson, the student will be able to: • *Demonstrate* an understanding of Ohm's Law.	By the end of this lesson, the student will be able to: • *Demonstrate* an understanding of Ohm's Law by designing an irrigation system to determine how much water pressure is needed to irrigate an area of crops. • *Model* this fluid system using an electrical schematic, to determine the pressure needed for the fluid to flow, as similar to the voltage for a current in a circuit.

Table III: Example of a Science Objective Compared to Engineering Concept Objective

It is important to note that there was not a one-to-one correspondence between the EEF codes and any one science content discipline in the state science standards analyzed. For example, we were not looking if merely the phrase "food and medicine" was used, but instead, we were investigating phrases that inferred the use of food or medicine with the intent of introducing engineering concepts. Examples of the phrase "food and medicine" might include, but is not limited to: genetic engineering, DNA manipulation of food products, or understanding how CAT scans work. The EEF codes outlined "core" engineering concepts that we believe students must understand (and/or perform) to be

State	Depth (w/o STS) Rank	Value
PA	**1**	**15**
MA	2	13
NY, VT	4	9
DE	5	8
WV	6	7
CT	7	6
NH,RI,OH	10	5
AK, ME, TX, NJ, WA	15	4
ID, MO, NM	18	3
IL, KY, LA, MI, ND, NE	24	2
CA,CO,DC, GA,IN,MD, SD,UT,WI, VA	36	1
AR,AZ,FL, HI,KS,MN, MS,MN,NC, NV,OK,OR, TN,WY	50	0

State	Depth (with STS) Rank	Value
PA	**1**	**18**
DE	2	16
MA	3	14
NY	4	12
VT	5	10
CT,OH,WV ,RI	9	9
NH	10	8
MD	11	7
FL,IN,TX	14	6
AK,ID,MO, NC,NM, WA	20	5
AZ,KY,IL, LA,ME,MI, ND,NJ,SC	29	4
AR,HI,NE, WI	33	3
AL,CO,GA, MN,UT	38	2
CA,DC,MS ,MN,MT, SD,VA,WY	46	1
KS,OK,OR, TN	50	0

State	Breadth Rank	Value
PA	**1**	**11**
DE, NY	3	7
OH,VT,WV	6	6
CT,MA,MD, NH,RI	11	5
AK,IN,ME, MI,MO,NC, NM,WA,SC	20	4
AZ,ID,KY, IL,LA,NC, NE,TX,WI	29	3
AL,CO,GA, FL,NJ,UT	35	2
AR,CA,DC, HI,MN,MS, MT,NV,SC, VA,WV	46	1
KS,OK,OR, TN	50	0

Table IV: Rankings of Each State by Depth & Breadth of EEF in Science Standards

Region (# of states/region)	**Region Average**
New England (N=6)	7
Mid-Atlantic (N=8 with DC)	5.9
Great Lakes (N=5)	2.2
Pacific (N=5)	1.8
Southwest (N=5)	1.4
Midwest (N=6 - no IA)	1.1
Mountain (N=5)	1.0
Southeast (N=10)	0.7

Table V: Breakdown by Region for Depth of EEF Content Standard Codes (Exclusive of STS)

considered an integrated science/engineering education. While some of these concepts are currently taught in a science curriculum (e.g. power and energy are taught in physics), from an engineering perspective, this understanding differs as applied to science and current technology in our society. In this analysis, we reviewed each state science standard through the lens of engineering while keeping in mind the content requirement in the science curriculum. As we reviewed each state science standard, we continually reassessed our understanding of this basic principle.

To better understand how this methodology was conducted, we provide an example of what we interpret as a "typical" science content objective found in a physics curriculum and our ideal of how an engineering concept might be integrated into this content objective. Although this example (Table III) is extensive, it demonstrates the differences between "typical" science objectives and the ideal integration of engineering concepts in science we envision. The science content objective in this example is Ohm's Law. Ohm's Law, and applying it to a circuit to calculate an unknown variable, is considered a content objective for "typical" physics curriculum. However, as written, it is not considered engineering per se. To write the objective of Ohm's Law through the lens of engineering, it is essential to understand that the engineering tries to address and satisfy a human need for a resulting behavior of a designed system. For example, an engineering problem using this content objective, Ohm's Law, would act as the "context" to teach this concept, and as such, would provide the students tackling this problem a deeper understanding of the law.

Note that this example provides a problem for the students to investigate, e.g. *human need for irrigation* (engineering context), while introducing the science concept that needs to be addressed from a typical physics curriculum. This example also demonstrates the use of modeling, a key component in engineering, thus using the connection of an electrical circuit and Ohm's Law for the model. Using the lens of engineering, the students will be developing higher order thinking skills and critical thinking in order to complete the engineering objective as stated.

During the analysis, we noted that the phrase "problem solving" was used continually throughout the state science standards. Using our example above, in a typical physical science class students' might be asked to, "solve a problem and determine the voltage needed for 2mA of current through two 50Ω resistors." In many science classes, it is a very real possibility that students were merely doing "cookbook" laboratory exercises assigned by the teacher. The use of engineering within the science curriculum fosters a different approach to curriculum design and teaching by advocating an inquiry approach to solving the problem. Since the purpose of this study is to determine how engineering might be integrated into state science standards, we sought evidence of the "intent" of engineering within each standard. We searched the documents for phrases that might indicate students'"investigating real world" problems in physics, such as, "developing their own circuit diagrams based on the physical fluid system" and/or "collecting data based on assumptions they made about their design to solve that given problem." These notations are classic engineering objectives. In an engineering curriculum, when students design products within constraints (as assigned by their teachers), they will begin to make intelligent decisions about the design by weighing trade-offs to increase the design's efficiency. This problem-solving example is similar to the challenges that an engineer encounters when posed with an engineering problem that needs to be solved. Throughout the analysis, we used this lens rigorously and judiciously.

Findings

The findings of this analysis indicate that there is an inconsistency in the incidence of engineering and technology concepts present in each state's science standard document. To determine the extent to which the EEF content strands were included in the states' science standards, two criteria were used; the *depth* of engineering content and the *breadth* of engineering content.

The *depth* of engineering content is defined as the *total number of times* each EEF code (Table 2) was identified in each science strand of the states' science standard's document. This analysis also included the influence that socio-economics (STS) had within the standard. The inclusion and exclusion of the STS code is noted in the tables and figures in this analysis and will be discussed later in this paper.

The *breadth* of engineering content is defined as the *total number of EEF content standard codes* found per state. As there are 13 EEF codes identified in Table II, each code would be counted only once. For example, consider a state that had a total of four EEF codes identified: three standards that were categorized as EN (environmental content standard code), and 1 categorized as STS. The value of the *depth* for that state would be 4 (or 3 if STS was excluded); the value of the *breadth* would be 2 (codes being EN and STS). The analysis presented in Table IV identifies and ranks each state by the *depth* of engineering content (with and without the inclusion of STS codes) and the *breadth* of engineering content found.

We were interested to note which region of the United States contained more EEF strands within the science content standards. We divided the U.S. into regions (trying to approximate equal number of states per region), and operationally defined each region as: Great Lakes (Illinois, Indiana, Michigan, Ohio, Wisconsin); Mid-Atlantic (Delaware, Maryland, New Jersey, New York, Pennsylvania, Virginia Washington, D.C., West Virginia); Mid-West (Kansas, Minnesota, Missouri, Nebraska, North Dakota, South Dakota,); Mountain (Colorado, Idaho, Montana, Utah, Wyoming); New England (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont); Pacific (Alaska, California, Hawaii, Oregon, Washington); Southeast (Alabama, Arkansas, Florida, Georgia, Louisiana, Kentucky, North Carolina, Mississippi, South Carolina, Tennessee); and, Southwest (Arizona, Nevada, New Mexico, Oklahoma, Texas). Table V displays how each region compared to the others. This ranking is based on the regional average of the *depth of EEF* codes, exclusive of STS.

It is important to note that with the exception of the top 3 regions, (e.g. New England, Mid-Atlantic and Great Lakes), the remaining 5 regional averages contain less than two EEF content standards per state. It is also worthwhile to note that the Southeast region averages less than one EEF content standard per state (there are 10 states in that region). It appears that the regions in the north/northeast have a deeper integration of engineering content in their science curriculums than the rest of the United States. Perhaps, this may be because, in part, of the abundance of manufacturing and technology companies within these regions as high schools ultimately begin the preparation for students to pursue jobs within this sector of the economy. Introducing students' to jobs in engineering through the use of EEF strands is advocated.

Next, we were interested to compare which of the EEF standards appeared most frequently in the state standards. Figure III demonstrated the total number of times each EEF code appeared across all states.

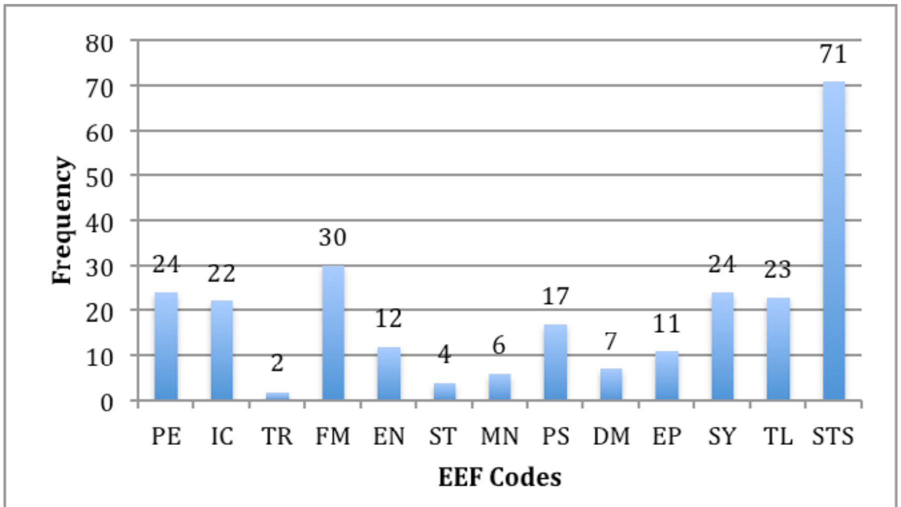

Figure III: Total # of EEF Codes in All States

Figure III demonstrates that the EEF content standard "food and medicine" (FM) was found most frequently across the state standards [n=30], followed by "power and energy" (FM) and "systems" (SY) [n=24], "engineering tools" (TL) [n=23] and "information & communication" (IC) [n=22]. We suggest that the engineering concepts in these areas correspond directly with science disciplines taught in a traditional science curriculum, e.g. food and medicine (FM) is found in biology disciplines and power and energy (PE) is found in physics disciplines. Since engineering tools (TL) incorporate models and simulations, it is often found in multiple science disciplines. A point of interest relates to the code, "systems" [SY]. Within the various engineering disciplines, the use and analysis of "systems" (SY) is the most common concept discussed and employed. The interaction of subcomponents to produce a functional system is a common lens used by all engineering disciplines for understanding, analysis, and design. The content strand SY is also the thread that permeates the EEF content strands. All regions of the United States, with the exception of the Southeast, have incorporated systems into their science curricula. We feel that, at a minimum, it is through the leverage of SY that curriculum designers can provide a platform for fostering and incorporating engineering content into science curricula.

An important observation in this data is the inordinately large incidence [n=71] of STS content found in the science standards across the country. It appears that the nexus between engineering concepts and states science standards revolves around socioeconomic issues (STS codes). This may be, in part, because of the influence of the science, technology and society (STS) movement in science education that began in the 1980s (Bybee, 2002). As state science standards incorporate technology into their science curriculums, they have used STS as the bridge between the disciplines of science and technology. We infer that this is the intent to implicitly embrace engineering education in science curricula. However, realizing the complexity of engineering, this falls short of the target. If the intent in science education is to educate a population that is scientifically literate, the need to also train the population to be technically literate is as vital. As we have previously argued, engineering education is the means to foster technical literacy.

Discussion and Conclusion

This research investigation explored to what extent 49 states and the District of Columbia integrate engineering content strands into their secondary science standards. This investigation represents the first step in assessing the extent of integration between the current state science standards and the engineering education principles. The EEF content standards (Koehler, et al., 2005) were designed to facilitate and promote engineering content strands that could be incorporated into the science and mathematics already established in secondary school curricula. In this analysis, the EEF content standards were refined to include additional content strands giving the document greater depth.

This analysis presents evidence that states in the northeast, mid-Atlantic and Great Lakes regions have a richer depth and breadth of engineering content integrated into their science standards than other regions of the United States. Some states, Pennsylvania, Massachusetts, New York and Vermont, have been applauded as having a comprehensive integration of technology and engineering concepts within their science education standards. These states have ranked higher than other states that differentiate and silo science content by disciplines (biology, chemistry, physics and earth science) and/or strands (inquiry in science, the nature of science) while tying in strands of technology sparingly.

This analysis establishes a measure to investigate how technology and engineering concepts play a role in current established science curricula. In this study, we propose a set of guidelines titled, Engineering Education Frameworks (EEF), that can accomplish the goal of integrating engineering concepts into the science content standards. By introducing such concepts into high school curriculum, it may result in fostering student interest in career opportunities in engineering and technology otherwise not introduced to the mainstream academic student. Since new science education reform documents, *A Framework for K-12 Science Education*, and the *Next Generation of Science Standards* have explicitly set forth content initiatives for including engineering design, process and understanding within science content, it is suggested that the EEF be a springboard for engineering topics to be consider in these new frameworks and standards (NRC, 2012; NRC, 2013).

This analysis reveals that every state in the U.S. currently focuses more on the societal impacts of technology and engineering instead of the fundamental content of engineering concepts. This indicates that less focus is aimed at student learning of the fundamentals of engineering and technology, perhaps inhibiting them in making informed decisions about a future in technology and engineering driven fields. From this analysis, it also reveals that engineering concepts are currently only marginally linked to traditional science standards. As noted previously, Pennsylvania, Massachusetts, New York and Vermont have already incorporated engineering and technology into their existing science standards and have explicitly outlined them as disciplines within their science standards. Ideally, these states are a model for other states to springboard into new, and perhaps untraditional areas of science curriculum such as STEM (science, technology, engineering and mathematics), so that the full breadth of engineering-oriented topics may be realized. Overall, the data suggests that engineering concepts are represented in science curriculum, albeit, minimally.

Recommendations and Implications

In order to achieve technical literacy for *all* students in high school, we advocate that the science curriculum writers identify engineering concepts as a *context* in which to teach science. As the new *Framework for K-12 Science Education* advocates, the crosscutting concepts that unify science and engineering and the practice of science and engineering will foster a change in the way we approach science in the K-12 setting (NRC, 2012). We suggest that the EEF document outline different areas of engineering that could be explored in the science classroom. The notion of teaching engineering design in the science classroom will only work if there is a topic in engineering to explore. The EEF provides the topics to be explored and describes the tools necessary to explore these topics. It is understood that most science teachers are not versed in the discipline of engineering and therefore, cannot be expected to teach engineering per se. However, using engineering topics as described in the EEF as a context in order to teach science, enhances both science content knowledge and provides a pathway toward technical and scientific literacy. To teach STS as the only means to interest students in technology, and peripherally engineering, is a potentially flawed strategy. Since it is essential to educate students for future positions in STEM careers and to introduce them to a 21st century skills base as a means to meet the increasing global economic needs, the K-12 arena is the essential battleground to begin this endeavor. We advocate integrating technology and engineering concepts into the already established and well-developed science curricula can accomplish this. But this training must go beyond the walls of the science classroom, as extensive professional development for science teachers must also take place. As engineering content is not part of the science teacher training programs, it is essential that teachers also have the opportunity to develop a deep understanding of how engineering concepts can be truly integrated into science disciplines. Extensive professional development must include not only pedagogical content knowledge in science, but also must include experiences working on engineering problems, developing units and lessons that integrate engineering and technology into science curricula, and perhaps, working with engineers in summer internships to understand their discipline. As research has indicated (Saunders, 2005) the effects of integrated instruction within the disciplines of STEM have shown that the context of design in an integrated curriculum (e.g. STEM) has improved students' motivation, interest and self-efficacy in these disciplines. Additionally, students who have been trained in an interdisciplinary approach to STEM fields have outperformed their counterparts in traditional science programs. It is through these continued efforts that science educators can enhance students' with interests in STEM careers, and encourage them to become leaders at the forefront of innovation and development to promote globalization.

As science educators develop and revise their science program of study, the inclusion of technology and engineering concepts as recommended by the current and new science education reform documents, could augment this curricula providing a context for the underlying science concepts to be taught. We contend that including the context of engineering and technology into the K-12 science curricula, as suggested in the EEF, can enhance the way science is taught and can provide relevance and interest for the students while also promoting technical and scientific literacy. We recommend and challenge science education to better align their curricular aims with technology and engineering education, and focus on integrating these STEM constructs into the science curriculum as a means to promote both technical and scientific literacy.

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