AC 2012-4941: BUILDING A FRAMEWORK TO EVALUATE THE INCLUSION OF ENGINEERING IN STATE K-12 STEM EDUCATION ACADEMIC STANDARDS

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Abstract
Over the past several years, the increased energy behind the Science, Technology, Engineering, & Mathematics (STEM) integration movement has inspired the addition of more engineering related content to the K-12 landscape. National standards for engineering are also just now coming into the landscape. As states begin to add engineering to their standards, the question becomes, "What constitutes a quality engineering education at the K-12 level?" Whether within a core math or science course, or as a stand alone program, certain approaches, problem solving strategies, and ethical or social considerations are unique to engineering and set it apart from those other subjects. Identifying those characteristics necessary for success in engineering education will help states, districts, schools, and teachers to evaluate the engineering skills and knowledge that they will be implementing in the classroom.

The purpose of this paper is to present the development of a framework to be used to assess academic standards related to engineering. Using the ABET Program Outcomes (Criteria 3 a-k) as our starting point, we examined the literature and national documents in the field related to each outcome, with particular focus on related K-12 literature. From this, we developed a framework for describing engineering content standards at the primary and secondary level. This paper will describe the development of the framework and how the framework can be used to assess STEM education academic standards at the state level.

I. Introduction

Robust K-12 engineering education is essential for helping to develop future generations of inventors and innovators who help to improve the world's health, happiness, comfort, and safety. Several national documents have called for integrating and improving K-12 engineering education, as well as developing a solid understanding of how K-12 engineering education should be structured and focused[1-5]. However, K-12 engineering education is especially problematic in STEM education since there is no well-established tradition of engineering in the K-12 curriculum[6]. A fundamental problem is the lack of standards for knowledge and skills for K-12 engineering education[1].

There are a number of unanswered questions surrounding the current state of K-12 engineering education. For example, *How is engineering taught in grades K-12?, How does engineering education 'interact' with other STEM subjects?, How has engineering been used as a context for exploring science, technology, and mathematics concepts?*[1] (p. 2). Knowing the current state of K-12 engineering education can serve to guide the development and structure of future K-12 engineering education standards and initiatives. The purpose of this paper is to describe the development of a framework based on the ABET Criteria 3 a-k and how it was used to describe K-12 engineering standards that are in place in fifteen states. The research questions investigated were:

1) How should a framework for assessing K-12 engineering education academic standards be developed?

2) Once developed, what are the results from using this framework on K-12 academic state standards that have included engineering?

II. Relevant literature

The foundation for the framework is the ABET Criteria 3 a-k (Table 1). ABET is a non-profit organization that accredits U.S and international post-secondary education programs in applied sciences, engineering, and technology. These ABET criteria describe quality characteristics of students who have completed undergraduate engineering programs and can serve to guide the future of K-12 engineering education. The literature was summarized for connections to each of the eleven ABET Criteria 3 a-k in order to begin to provide further description for each criteria at the K-12 level. The elaboration of the ABET Criteria from the relevant literature provides further support for the argument of using the Criteria a-k as a framework to assess K-12 academic standards.

Table 1. ABET Program Outcomes (Criteria 3 a-k)

(a) an ability to apply knowledge of mathematics, science, and engineering. (b) an ability to design and conduct experiments, as well as to analyze and interpret data (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability. (d) an ability to function on multidisciplinary teams (e) an ability to identify, formulate, and solve engineering problems (f) an understanding of professional and ethical responsibility (g) an ability to communicate effectively (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context (i) a recognition of the need for, and an ability to engage in life-long learning (j) a knowledge of contemporary issues (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

(a) an ability to apply knowledge of mathematics, science, and engineering.

The craft of engineering requires the direct application of mathematics, science, and technology content and skills. While technology is not included in ABET 3-(a) it appeared frequently in the literature in relation to K-12 engineering education, meriting the addition of technology to this discussion. Two main themes emerged from the literature. The first key point is that the STEM disciplines overlap and are fundamentally related. Furthermore, it was argued that adding engineering concepts and projects to mathematics, science, and technology curricula have benefits for both learning outcomes and students' interest in the STEM subjects[7-10].

Many agree that engineers must be able to apply different aspects of mathematics, science, and technology[1, 5, 11-12]. Chae, Purzer, and Cardella[13], for example, list the ability to apply science, math, and technology in problem solving as one of the core concepts of engineering literacy. The subjects are so related, however that Lewis[14] believes stand-alone engineering education is not necessary at the K-12 level. Others as well have advocated for adding engineering concepts to mathematics, science, and technology courses[5, 8, 14-16]. However, Katehi et al.[1], in their summary of the current state of K-12 engineering education, note that these natural connections between the subjects are not always emphasized. Though engineering in practice requires application of mathematics and science, current engineering education is limited in scope. Science is treated only as a tool and math is used mainly for data analysis[1].

One of the benefits of introducing engineering (in particular engineering design) into the mathematics and science curricula is an increased interest in STEM subjects and careers in STEM fields. Several studies found an increase in students' interest in these areas after implementing engineering design into K-12 science and mathematics classes[7-10, 17]. There was also an increase found in students' interest and attitudes in STEM subjects in studies that involved curriculum used as extra curricular programs such as Adventure Engineering[18], Engineering is Elementary[19], and In the Middle of Engineering[19].

The improvement of student learning in mathematics and science is a common claim for the integration of engineering in K-12 education[1, 20-21]. Olds, Harrell, and Valente[9] found an increase in students' understanding of simple machines after implementing an engineering design activity into a middle school science class. Apedoe, Reynolds, Ellefson, and Schunn[7] found an increase in students' understanding of atomic interactions and energy after implementing an engineering design activity in a high school chemistry class.

(b) an ability to design and conduct experiments, as well as to analyze and interpret data

An ability to design and conduct experiments, as well as to analyze and interpret data is related to scientific inquiry. Scientific inquiry, as a pedagogy, is an integral part of science education and is very connected to the ways one should integrate engineering in K-12. However, the purpose of each is different. Engineering design is focused on a product or process as the end goal, whereas scientific inquiry is a methodology to understand the natural world. Inquiry-based or discovery learning in K-12 classrooms is a way to improve mathematics and science education[22-23] and existing K-12 engineering education curricula already consider inquiry an integral part of engineering education[18, 24]. The design process and inquiry both require high level reasoning and creativity[11, 20]. However, design deals more with constraints, trade-offs, and optimization while inquiry can focus more on generalizations[1].

(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.

In 2010, NAE released the document *Standards for a K-12 Engineering Education?,* in which design is defined as "an iterative process that begins with the identification of a problem and ends with a solution that takes into account the identified constraints and meets specification for desired performance"[5] (p. 6-7). Engineering design involves the following essential components: identifying the problem, specifying the requirements of the solution, decomposing the system, generating a solution, testing the solution, sketching and visualizing the solution, modeling and analyzing the solution, evaluating alternative solutions as necessary, and optimizing the final design[1]. Engineering as a field is centered around the design of products or systems within given constraints.

The concept of engineering design in K-12 engineering education is prevalent within the research and has benefits in terms of content knowledge and process skills for students[7, 11, 13, 15-16, 20-21, 25-27]. Engineering design is often seen as a pedagogical approach to be used for STEM education because it is a way to identify and solve problems. The design process is highly iterative, has the possibility of multiple solutions, is conducted in a meaningful context for mathematics, and can be a stimulus to systems thinking, modeling and analysis[1]. Engineering design integrates standards from other subjects, which gives engineering education significant merit[28]. It requires the application of content knowledge and cognitive processes to design, analyze, and troubleshoot complex systems in order to meet society's needs. It has been found that inquiry based science and math instruction using a design context can develop learners' competencies including cognitive models of how systems work, communication skills, the ability to synthesize ideas, STEM knowledge, and the ability to evaluate designs[20].

(d) an ability to function on multidisciplinary teams

An integral part of the work of engineers and most professions is the ability to work effectively in teams. Engineers often collaborate with people from various fields in order to effectively design solutions. One of three general principles that have been proposed for K-12 engineering education is to promote engineering habits of mind, which include collaboration[1]. K-12 engineering education should involve students working in teams on design activities in order to improve teamwork skills[1, 21, 29]. We also know from years of work on cooperative learning that this is an important pedagogy for all students in K-12 education[30-32].

(e) an ability to identify, formulate, and solve engineering problems

Problem solving through the design process is at the heart of engineering education. Primary reasons for teaching engineering in K-12 include enhancing science and mathematics education, addressing technology literacy needs, and improving students' critical thinking. Critical thinking skills can be improved by engaging students in hands-on engineering and design activities intended to foster knowledge, skills development, and problem solving[1]. Problem solving has been included in a list of the ten best practices for teaching science and mathematics[23] and is equally important for K-12 engineering and integrated STEM education.

K-12 engineering education enriches students' problem solving by ensuring that it is done in real world contexts. "Design is an iterative process that begins with the identification of a problem and ends with a solution that takes into account the identified constraints and meets specifications for desired performance" [5] (p. 6-7). Through the iterative process students may identify, formulate, and solve new engineering problems and realize that there are multiple solution strategies. What makes engineering design problems rich is that the problems do not have single, correct solutions and involve creativity[5]. An engineering focus can put problem solving into real-world contexts.

(f) an understanding of professional and ethical responsibility

Understanding of ethical responsibility is mentioned in regards to K-12 engineering education, however, further elaboration is not provided on what this should include. A document released in 2004 by the National Academy of Engineering titled, *The Engineer of 2020: Visions of Engineering in the New Century*[33], suggests that an engineer should be someone who will be "broadly educated, who see themselves as global citizens, who can be leaders in business and public service, and who are ethically grounded" (p. 5). In order for future engineers to be ethically grounded, ethical issues should be an undertaking in K-12 engineering projects[15]. This can be enhanced by having students think about ethical considerations while solving problems that they might face in their everyday life[6, 13].

(g) an ability to communicate effectively

Effective communication in multiple modalities is an essential skill for an engineer. The 2009 National Academy of Engineering report, *Engineering in K–12 Education: Understanding the Status and Improving the Prospects*[1], states that the expectations for engineering students must include the ability to work well in teams, to communicate ideas effectively, and to understand other cultures. Engineering students tend to think that mathematics is the language of engineering. However, several languages or representations are used in design including verbal or textual statements, graphical representations, mathematical or analytical models, and geometry related rules and features of shapes. Design thinking is a complex processes that involves working collaboratively on teams in a social process and "speaking" several languages with each other [11]. It is vital that both verbal and written communication is clearly expressed throughout the design process in order to develop an effective solution.

(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context

K-12 engineering education should help students understand the broad context in which engineering is practiced and that engineering is not just solving straightforward, narrow analytical problems[34-35]. A core concept of engineering literacy that has been proposed is for students to understand and explain how basic societal needs (e.g., water, food, and energy) are processed, produced, and transported to solve basic problems faced in everyday life[13]. The manner in which these basic needs are met has a profound impact on global, economic, and environmental issues.

Society is continually changing and engineers must adapt to these changes. Engineers must use advances in science to develop technologies that benefit humankind, meet the growing need for interdisciplinary approaches, while remembering that engineering is particularly sensitive to globalization and global conflict because it speaks through an international language of mathematics, science, and technology[33]. K-12 engineering education can support the acquisition of a wide range of knowledge and skills associated with comprehending and using STEM knowledge to accomplish real world problem solving to help students understand the impact of engineered solutions in their school, community, state, country, and world.

(i) a recognition of the need for, and an ability to engage in life-long learning

K-12 engineering education should instill in students the desire for life-long learning. Technology is rapidly changing, which makes it essential for engineers to continue to be devoted to learning and finding new applications of mathematics and science. The interdisciplinary nature of the work of engineers also makes engineers often have to explore new horizons and form new collaborations.

Engineering education in K-12 has shown the potential for engaging more students in mathematics and science. A study that involved faculty from the University of Nevada, Reno paired with middle school science teachers explored how engineering could be incorporated in science classrooms. After implementing engineering activities the science teachers found that students who were not usually engaged in science were actively engaged in the design process[8]. Similarly, Mooney, & Laubach[18] found that 5th to 9th grade students that participated in Adventure Engineering, a science and mathematics outreach initiative, showed an increased interest and enthusiasm for learning.

Engineering education in K-12 has begun to show the potential for encouraging valuable life-long learning skills in students. Benefits of engineering experiences for students include learning how to sift through details to find essential information[34], developing multiple solutions[34], trouble shooting and learning from failure[15], teamwork and communication skills[1, 10], leadership skills[1], and the ability to work with a diverse group of people[1]. These skills can help students to continue to learn and be successful in our technologically based, data driven world.

The importance of implementing K-12 engineering education in order to develop students' interest in engineering careers is summarized by the positioning statement developed by the National Academies Press[12] for improving the public perception of engineering:

> No profession unleashes the spirit of innovation like engineering. From research to real-world applications, engineers constantly discover how to improve our lives by creating bold new solutions that connect science to life in unexpected, forward-thinking ways. Few professions turn so many ideas into so many realities. Few have such a direct and positive effect on people's everyday lives. We are counting on engineers and their imaginations to help us meet the needs of the 21st century" (p.5).

However, only a few engineering curricula define their objective as teaching engineering concepts and skills to prepare young people for further education and engineering careers[1].

(j) a knowledge of contemporary issues

The lack of diversity in engineering education is a major problem[1, 36-37] and K-12 engineering curricula and programs should be developed with special attention to features that appeal to students from underrepresented groups[1, 19]. A recommendation for the advancement of engineering in P-12 classrooms is for students to develop interest and awareness in what engineering is and what engineers do[20]. When students are exposed to the variety of fields of engineering and begin to think of engineering as a possible career at a younger age, this may help to increase the diversity of engineers. Engineers are involved in a variety of fields that involve contemporary issues including the environment, homeland security, information technology, global communications, medical devices, medicine, and transportation.

A well-defined understanding of engineering is essential in that new ideas and designs depend on the ability to attract and retain workers in a variety of engineering fields. One of the core concepts of engineering literacy proposed by Chae, Purzer, & Cardella[13] is for students to discuss, critique, and make decisions about national, local, and personal issues that involve engineering solutions. Similarly, a few of the messages that were rated the most favorable during focus group interviews by students and parents in the National Academies Press report on improving the perception of engineering were that engineers make a world of difference and engineering is essential to our health, happiness, and safety[3].

(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Engineers use applications of mathematics and science to develop technological tools that can be used to improve our daily lives. Students in K-12 can begin to understand and use various techniques and skills through design-oriented activities including plans, background research, prototypes, drawings, and Computer Aided Design (CAD) programs.

The work of engineers is central to the development of technology. However, high schools that provide technology education are becoming more rare[38]. It has been recommended that technology education should be refocused on engineering design[16, 39]. Several benefits have been proposed for technology education to focus on engineering design including that engineering design would elevate the field of technology education to a higher academic level and engineering design provides an ideal platform for integrating mathematics, science, and technology[40]. In whatever setting the knowledge of engineering techniques, skills, and tools are developed the focus needs to be on improving students' understanding and appreciation of the technological world while deepening their knowledge in mathematics and science.

The understanding of the central role of materials and their properties is an essential feature of engineering solutions[15]. Design activities require learners to notice and reflect on the structure, function, and behavior of a process, a device, or a natural phenomena[20]. Scientific knowledge informs engineering design and many scientific advances would not be possible without technological tools developed by engineering[1]. However, most people have little understanding of the technology they use in their everyday life[26].

An analysis of 1,600 middle school students' drawings and explanations of engineers at work found that the most common objects students included in their drawings were passenger vehicles, civil structures, and building tools. Only 10 percent of pictures included engineers designing. The results "suggest that there is apparently a lack of any perception of engineering in some groups of the middle school student population that provided data for this study"[41] (p. 67). More work is needed to help students understand how engineers design and use technological tools in their work.

In current K-12 engineering education curricula, technologies are presented differently. In some curricula, technologies are presented as concrete example of scientific principles, such as technologies ranging from ancient bricks and clay pots to modern tennis rackets. Some curricula are designed to improve technological literacy, such as Engineering is Elementary which taps into children's natural curiosity to promote the learning of engineering and technology concepts[1]. The importance of technological literacy for individuals has increased due to the decisions that can be made due to the influx of technological tools[1]. It is important that K-12 engineering education expose students to how applications of mathematics and science can be used with the techniques and skills of engineering practice to design and use technological tools.

III. Development of the framework

The literature was used to guide the development of the framework through creation of initial definitions of each of the 11 ABET outcomes as they related to K-12 education. Document content analysis[42] was completed on state academic standards. States were selected based on the study done by Strobel, Carr, Martinez-Lopez, & Bravo[43] in which they used a computerized search program to determine that fifteen states had explicit engineering standards. Engineering standards were The framework was then further developed to assess K-12 academic standards. through discussions of the initial coding of the 15 states with explicit engineering standards.

The research team consisted of one professor of STEM education and four graduate researchers. Two of the graduate researchers were from mathematics education and two were from science education – one of the science education researchers also had a master's degree in engineering. Each member of the research team had K-12 teaching experience.. The research team chose to look at all of the content standards in each of the STEM disciplines for evidence of engineering. These academic standards fell within the specific content areas of mathematics, science, information and technology education, and career and technical education. The state standard documents in those identified content areas were then analyzed and coded to identify how those engineering related standards could be classified under each of the initial definitions for the 11 ABET criteria. The ABET criteria are designed to be used to define what an engineer does from professionalism to technical competency and therefore each criterion is set within an engineering context. To ensure that our coding reflected how state standards directly addressed engineering education, it was decided to only code a standard if it met the ABET criterion within an engineering context. A standard was determined to have an engineering context, if engineering was mentioned in the strand title, course title or the standard or benchmark directly mentioned engineering or engineering design. Standards and benchmarks of standards (or its equivalent term) were used as the unit of coding.

The coding process began with the research team coding the Massachusetts academic standards. Massachusetts was selected as the first state to be coded because they were the first state to have required engineering standards included in all grades from K-12th grade. Through discussions of the codes by the research team, the descriptions of the ABET program outcomes with respect to K-12 education were re-written.

Through this process it became evident that the distinction between ABET 3-(c) and ABET 3-(e) as well as between ABET 3-(h) and ABET 3-(j) was not clear when considering K-12 education. Through discussions within the research team, it was decided to combine ABET 3-(c) and ABET 3-(e) as well as ABET 3-(h) and ABET 3-(j). ABET 3-(c) and ABET 3-(e) were combined based on the rationale that engineering design is a specific approach to problem solving. They are also closely related because throughout the design process new engineering problems are identified, formulated, and solved. Also, when problem solving was mentioned in the academic standards, it was not in reference to engineering, but to mathematics or science. ABET 3-(h) and ABET 3-(j) were combined based on the rationale that both of these standards involved contemporary issues because contemporary issues involve global, economic, environmental, and societal contexts. Engineers must take these issues into account when designing solutions to help improve the lives of humans.

Massachusetts was the only state to be coded by all four graduate researchers, the other fourteen states were coded in pairs by one of the science education graduate researchers and one of the mathematics education graduate researchers. Through the discussions to reach final agreement for these fourteen states further refinements and additions were made to the framework (Table 2). Each ABET standard has a description for K-12, example standard(s), and an explanation of why the standard was coded. Technology was added to ABET 3-(a) based on suggestions from the literature that focused on STEM education. ABET 3-(i) did not appear in any of the Massachusetts standards so this first appeared in the next state that was coded, Texas. Massachusetts also includes suggested learning activities with their science standards to provide further information for how the standards should be taught and these were used to inform the coding.

Table 2. ABET-based K-12 engineering standards coding framework.

ABET Criteria 3 standard adapted for K-12	Description	Example Standards	Explanation
(a) An ability to apply knowledge of mathematics, (technology), science, and engineering	For this standard the STEM knowledge had to be explicitly applied in situations that involve engineering. Technology was added to the ABET standard because applying knowledge of technology is essential as well as mathematics and science. Universal systems model as an application of technology.	Massachusetts Technology/Engineering standard (grades 6th-8th) 6.4 Identify and explain lift, drag, friction, thrust, and gravity in a vehicle or device, e.g., cars, boats, airplanes, rockets.	To meet this standard students would have to demonstrate the ability to apply their STM knowledge of the specific concepts of lift, drag, friction, thrust, gravity, and transportation to explain how different transportation systems work. [This standard was also coded (g).]
(b) An ability to design and conduct experiments, as well as to analyze and interpret data	This standard focuses on experimentation, testing, and working with collected data in engineering contexts.	Massachusetts Technology/Engineering standard (grades 3rd-5th) 1.1 Identify materials used to accomplish a design task based on a specific property, e.g., strength, hardness, and flexibility.	The emphasis of testing materials for an engineering design allowed this standard to be coded. One of the suggested learning activities suggests students be given a variety of objects made of different materials, ask questions and make predictions about the hardness, flexibility, and strength of each, then to test to see if the predictions are correct. [This standard was also

			coded (a) &(ce).]
(c/e) An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, healthy and safety, manufacturability, and sustainability. And an ability to identify, formulate, and solve engineering problems.	Problem solving and design are closely related in that design is a more specific approach to problem solving. However, throughout the design process new engineering problems can be identified and formulated. Standards that referred to part of the design process, including troubleshooting, were coded as well.	Massachusetts Technology/Engineering standard (grades 6th-8th) 2.1 Identify and explain the steps of the engineering design process, i.e., identify the need or problem, research the problem, develop possible solutions, select the best possible solution(s), construct a prototype, test and evaluate, communicate the solution(s), and redesign. Massachusetts Technology/Engineering standard (grades 6th-8th) 2.5 Explain how such design features as size, shape, weight, function, and cost limitations would affect the construction of a given prototype.	This standard emphasizes students ability to know and explain what would happen in the engineering design process. The suggested learning activities demonstrate that this knowledge would be gained through working through the design process to design and test a prototype while meeting design constraints. [This standard was also coded (a), (b), (g), (hj) & (k).] Problem solving is required in order to identify and formulate engineering problems for a prototype related to various constraints. [This standard was also coded (a), (b), (g), (hj), & (k).]
(d) An ability to function on multidisciplinary teams	Teamwork, collaboration, and valuing diverse viewpoints and strategies were the emphasis of this standard.	Massachusetts Technology/Engineering standard (grades 6th-8th) 6.3 Identify and describe three subsytems of a transportation vehicle or device, i.e., structural, propulsion, guidance, suspension, control, and support.	While this standard does not explicitly state teamwork, one of the suggested learning activities involves group discussion and working in teams to draw a design of a future transportation mode.[This standard was also coded (a), (g), & (k).]
(f) An understanding of professional and ethical responsibility	This standard relates to moral principles that engineers can abide by to properly serve society, their clients, and their profession. This could include intellectual property, legal restrictions, governmental regulations, and designing products for reliability and safety.	Massachusetts Technology/Engineering standard (grades 9th-12th) 2.6 Recognize the purposes of zoning laws and building codes in the design and use of structures.	To meet this standard students would learn the purposes of building and designing structures to code in order to ensure safe living quarters.[This standard was also coded (a) and (hj).]
(g) An ability to communicate effectively	Both written and verbal communication were included in this standard. This could be indicated by the use of various verbs including describe, explain, and demonstrate. Effective technical writing	Massachusetts Technology/Engineering standard (grades 6th-8th) 2.3 Describe and explain the purpose of a given prototype	The verbs describe and explain necessitate effective communication to meet this standard. [This standard was also coded (k).]

	was also included.		
(h/j) The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context. And a knowledge of contemporary issues.	Both standards relate to contemporary issues (problems of today) such as transportation, water, energy, gender, equity, policies, and understanding the diverse fields that can benefit from the work of engineers. This standard also included understanding the broad impact of engineering solutions for various interacting factors.	Massachusetts Technology/Engineering standard (grades 3rd-5th) 2.4 Compare natural systems with mechanical systems that are designed to serve similar purposes, e.g., a bird's wings as compared to an airplane's wings. Massachusetts Engineering/Technology Standard (3rd -5th grade) 2.1 Identify a problem that reflects the need for shelter, storage, or convenience.	Engineered solutions that have been based on nature have had a powerful impact in the world. Airplanes are mentioned in the standards and the impact of boat designs are mentioned in the suggested learning activities. [This standard was also coded (a), (b), (ce), and (g).] The need for shelter is a contemporary issue that affects people in many different countries. [This standard was also coded (ce).]
(i) A recognition of the need for, and ability to engage in life-long learning	With rapidly changing technology and global issues engineers must be life-long learners. This standard focuses on understanding the careers that are available in STEM fields. This could include job shadowing, mentoring, and apprenticeship training for future engineering careers.	Texas Concepts of Engineering and Technology (9th -10th) 1E Compare and contrast engineering, science, and technology careers.	Students can begin to develop skills to help them gain interest and awareness of careers in STEM fields. [This standard was not coded any other ABET standards.]
(k) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	Tools and skills can involve CAD programs, drawings, plans, patent process, engineer notebooks, planning and time lines, background research, prototypes, and techniques related to modeling and optimizing solutions.	Massachusetts Engineering/Technology Standard (3rd -5th grade) 1.2 Identify and explain the appropriate materials and tools (e.g., hammer, screwdriver, pliers, tape measure, screws, nails, and other mechanical fasteners) to construct a given prototype safely.	The standard would require students to know what certain tools are and how they can be used to build a prototype or a design. [This standard was also coded (g).]

Interrater reliability was assessed using Cohen's Kappa (κ)[44]. Cohen's κ was calculated only for the 14 states other than Massachusetts as Massachusetts State Academic Standards were coded together as one of the mechanisms used to further develop our descriptions of our codes (which leads to 100% coding agreement). For these 14 states' data, the agreement was calculated on the first pass at each item in the standards, although 100% agreement was negotiated after discussion. The interrater reliability for this study was $\kappa = 0.977$ with the standard error of kappa being $SE\kappa = 0.001$. The strength of this agreement is very good.

IV. Results and discussion

The results of the coding will be discussed by describing where engineering appeared in each of the fifteen states and then by summarizing the number of ABET standards that were connected to the engineering standards in each state. Overall, the results show that the state content standards based on our framework are focused on the ability to apply STEM knowledge in engineering contexts, engineering design and problem solving, and effective communication. However, teamwork, ethics, and life long learning do not often appear in the standards.

Table 3 has a summary of what subject areas and grade levels engineering appeared in each of the fifteen states as well as the percentage of benchmarks for each subject area that were coded as engineering. For example, engineering appeared in 25% of the K-12th grade science standards in Massachusetts. Massachusetts's Career Technical education standards do not include a percentage because the engineering standards were not different from the engineering standards embedded in the science standards. Connecticut's Career Technical education standards listed five classes that had engineering in the titles, but provided no standards or additional information for these classes.

Table 3. Summary of where engineering appeared in the fifteen states' STEM academic standards.

	Type of Academic State Standards			
State	Science	Mathematics	Information & Technology	Career & Technical
Alabama				9th-12th (1%)
California				7th-12th (9%)
Connecticut	8th (2%)			9th-12th
Georgia				9th-12th (1%)
Idaho			K-12th (21%)	
Indiana	K-8th (6%)			6th-12th (58%)
Maryland	P-12th (3%)			6th-12th (29%)
Massachusetts	K-12th	9th-12th		9th-12th

	(25%)	(< 1%)		
Minnesota	K-12th (17%)			
Mississippi				6th-8th (<1%)
New York	K-12th (8%)			K-12th (13%)
Ohio			K-12th (31%)	9th-12th (25%)
Oregon	K-8th (23%)			
Tennessee	K-12th (18%)			6th-12th (5%)
Texas				9th-12th (6%)

Of the four content areas that were investigated, engineering was most prevalent in states' career technical education standards (12 states) and science standards (8 states). However, engineering appeared in more grades in the states' science standards as opposed to the career technical education standards. The career technical education standards were mostly for elective classes as well. The least prevalent appearance of engineering was in the mathematics standards (1 state). The Common Core State Standards for Mathematics do not contain engineering and of the fifteen states only Minnesota and Texas have not adopted the Common Core State Standards for Mathematics. As an interesting side note, the Common Core State Standards for Mathematics do include modeling as a standard for all grades in mathematics, which is a natural place to integrate engineering and mathematics.

Each state had varying amounts of standards for each content area. So the percentage of engineering in each content area only tells part of the story. Tables 4 to 7 provide greater detail as to the number of engineering standards in each subject and the specific ABET standards that were connected to these standards.

Table 4 lists the states that had engineering in their science standards and the total number of standards that had engineering. The percent in parentheses next to the total number of standards gives the percent of the total science standards that contained engineering. For example, Connecticut had 18 science standards with engineering, which was two percent of the science standards. The numbers underneath the ABET standards gives the percent of those 18 engineering standards that were coded for each ABET standard.

Table 4. Summary of ABET-based K-12 engineering standard codes from state science standards.

	ABET-based K-12 engineering codes								
State (Total standards)	**a**	**b**	**c/e**	**d**	**f**	**g**	**h/j**	**i**	**k**
Connecticut 18 (2%)	100%	6%	11%	0%	11%	11%	0%	0%	11%
Indiana 44 (6%)	61%	7%	25%	0%	0%	14%	7%	0%	7%
Maryland 42 (3%)	62%	5%	45%	2%	5%	48%	5%	0%	36%
Massachusetts 90 (25%)	73%	11%	39%	3%	1%	71%	32%	0%	30%
Minnesota 81 (17%)	67%	10%	15%	0%	2%	32%	35%	2%	2%
New York 76 (8%)	43%	18%	93%	4%	0%	0%	29%	18%	29%
Oregon 42 (23%)	19%	14%	74%	2%	2%	31%	24%	0%	10%
Tennessee 165 (18%)	74%	23%	51%	0%	1%	40%	60%	0%	26%

Overall, the ABET standards that had the greatest percentage were (a),(c/e), and (g). These ABET standards emphasize applying STEM knowledge in engineering contexts, engineering design and problem solving, and effective communication. ABET (d),(f), and (i) were not included much at all. There was rarely any mention of building teamwork skills, ethical considerations in engineering, and knowledge of career opportunities in engineering.

Massachusetts was the only state that was found to have engineering in their mathematics standards. There was one standard that appeared in the classes of Modeling Math I, Modeling Math II, and Modeling Math III. The standard stated that students should be able to apply geometric methods to solve design problems (e.g., designing an object or structure to satisfy physical constraints or minimize cost; working with typographic grid systems based on ratios). Table 5 lists the ABET standards that were connected with this standard.

Table 5. Summary of ABET-based K-12 engineering standard codes from state math standards.

	ABET-based K-12 engineering codes								
State (Total Standards)	**a**	**b**	**c/e**	**d**	**f**	**g**	**h/j**	**i**	**k**
Massachusetts 3 (<1%)	100%	0%	100%	0%	0%	100%	0%	0%	0%

Two states had information and technology standards that included engineering (Table 6). Similarly to the science standards ABET 3-(a), 3-(c/e), and 3-(g) were the main focus. In the IT and career and technical education standards ABET 3-(k) received a greater focus with an emphasis on CAD, drawings, prototypes, and techniques related to modeling.

Table 6. Summary of ABET-based K-12 engineering standard codes from state information and technology standards.

	ABET-based K-12 engineering codes								
State (Total Standards)	**a**	**b**	**c/e**	**d**	**f**	**g**	**h/j**	**i**	**k**
Idaho 13 (21%)	54%	0%	69%	31%	0%	46%	0%	0%	31%
Ohio 32 (31%)	63%	3%	47%	3%	0%	38%	13%	3%	16%

The career and technical education standards had a focus on ABET standards 3-(a), 3-(c/e), 3-(g), and 3-(k) (Table 7). Some of the states placed a greater emphasis on ABET (d) and ABET (h/j). Teamwork and the impact of engineering solutions in global, social, environmental, and economic contexts could have been included more in the science, mathematics, and IT standards.

Table 7. Summary of ABET-based K-12 engineering standard codes from state career and technical education standards.

	ABET-based K-12 engineering codes								
State (Total Standards)	**a**	**b**	**c/e**	**d**	**f**	**g**	**h/j**	**i**	**k**
Alabama 45 (1%)	60%	7%	16%	4%	11%	73%	16%	4%	22%
California 220 (9%)	43%	10%	25%	<1%	2%	8%	9%	1%	35%
Georgia 271 (1%)	35%	4%	25%	7%	1%	40%	12%	7%	31%
Indiana 11(58%)	73%	9%	55%	27%	0%	82%	64%	0%	36%
Maryland 62 (29%)	58%	34%	79%	5%	5%	87%	37%	0%	39%
Mississippi 6 (<1%)	50%	17%	83%	33%	0%	100%	33%	0%	50%
New York 12 (13%)	8%	0%	50%	0%	0%	50%	0%	75%	25%
Ohio 32 (25%)	63%	3%	47%	3%	0%	38%	13%	3%	16%
Tennessee 372 (5%)	32%	6%	24%	10%	6%	365	18%	5%	13%
Texas 633 (6%)	40%	2%	19%	8%	9%	30%	8%	8%	22%

Finally, the overall percentage of codes for the combined 15 states and all math, science, information and technology, and career and technical education standards are provided. Figure 1 presents a chart that demonstrates the frequency of the codes. Note that the columns do not sum to 100% because many standards and/or benchmarks were coded with multiple codes. Also, only standards and benchmarks that had at least one code are included in this summary figure (N=2948).

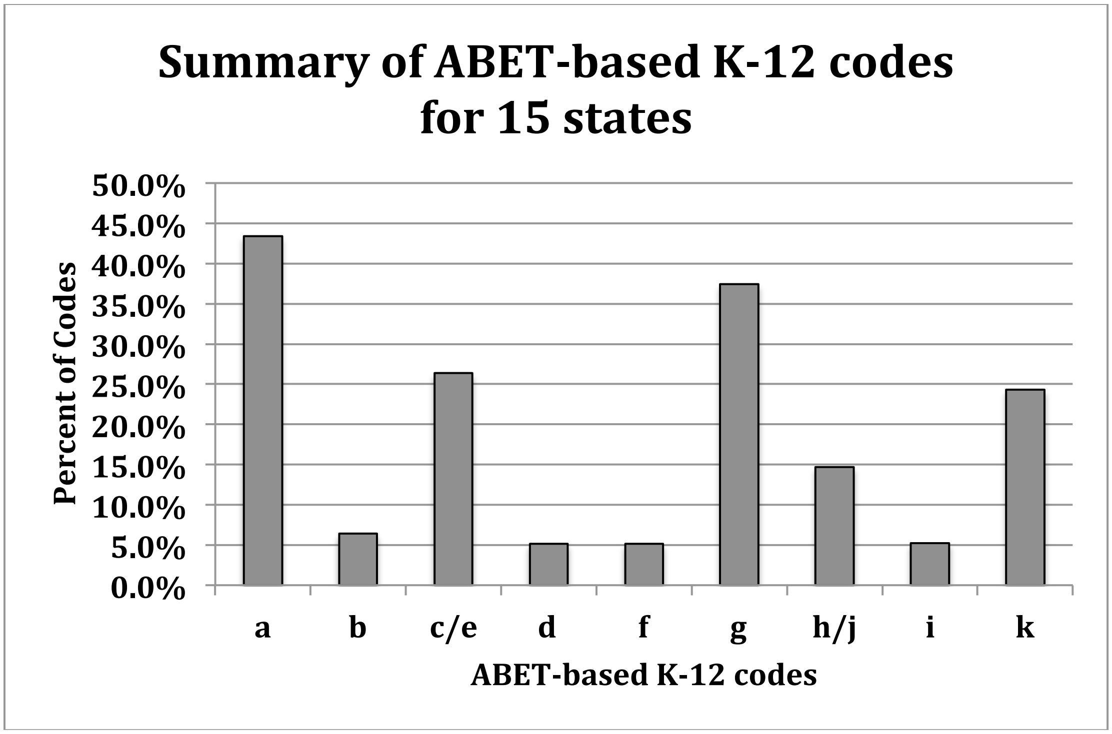

Figure 1. Bar chart to visually represent the frequency of codes in the entire population.

Here, code (a) was the most frequent code at 43.4% (1280) of coded standards. This code represents the ability to apply STEM knowledge. The second most frequent code is (g) at 37.7% (1103) of coded standards. This represents the ability to communicate effectively. Hovering near 25% are codes (c/e) and (k). Code (c/e) represents engineering design and problem solving, and code (k) represents the use of techniques, skills, and tools of modern engineering. Code (c/e) represents 26.4% (777) and code (k) represents 24.3% (717) of the coded standards and benchmarks. Code (h/j), the code for the impact of engineering solutions and a knowledge of contemporary issues, represents 14.7% (433) of the coded standards and benchmarks. The remaining four codes (b), (d), (f), and (i), were all minimally represented at 6.4% (189), 5.1% (151), 5.1% (151), and 5.2% (154), respectively.

The higher frequency codes, (a) and (c/e) were expected, as these codes represent the integration of engineering with other subjects in K-12, which is an assumption especially for the states where engineering standards were embedded in the science or mathematics standards, and engineering design, which is the main defining characteristic of engineering. The high frequency of code (g) was less expected, but a welcomed finding. Communication (written and spoken) is a difficult skill for students to learn. The national push for reading and writing across the curriculum is supported by these standards. In addition, good communication skills are important, not only for STEM professionals, but for all of society.

The less frequent codes of (b), (d), (f), and (i) were also expected. However, the authors of this paper feel that this oversight demonstrates a lack of total understanding of engineering by the writers of the standards and the policy makers in these 15 states. In particular, the authors would have liked to see a much higher representation of code (d), working on multidisciplinary teams, and code (f), the ethical responsibilities of the engineer. As we know from post-secondary engineering education, these are two very difficult ideas to teach to students. It would be preferable to begin this education at a younger age. Teamwork in engineering, or in any subject for that matter, is an invaluable life skill that will help our students succeed in society. The ethics portion of engineering brings in the societal issues that should surround all engineering designs and allows students to think about the ethics of design from both sides, the engineer and the community. Code (b), an ability to design and conduct experiments, being infrequent was not as surprising, especially since at the K-12 level many of the engineering standards were embedded in science standards. Standards and benchmarks that addressed the design of experiments were often not couched within the engineering standards, but were in the science standards. Another plausible explanation for the lack of this code could be that the design of experiments is often included as part of the testing phase of engineering design processes. Finally, the lack of engineering standards that addressed the life-long learning code (i) was also not expected to be prevalent in the K-12 academic standards. The reason for this was because the nature of this code is to prepare undergraduate engineers to recognize that additional education is necessary in the workplace and that is not commonly addressed in academic standards, especially at the K-12 level. .

V. Conclusion

The results of the coding of the fifteen states identified as having engineering in their academic standards revealed the areas that these states have chosen to highlight in their engineering education. There is agreement among the states that the ability to apply STEM knowledge in engineering contexts, engineering design and problem solving, and effective communication are important components of K-12 engineering education as these ABET standards were frequently found in the state standards. Teamwork, ethics, and life long learning do not appear frequently in the standards, which suggests that states are not highlighting these practices in the implementation of engineering education, though the literature demonstrated that these are important aspects of K-12 engineering education.

Along with the other ABET standards detailed in the framework, quality K-12 engineering education should have a focus on students' ability to apply mathematics and science knowledge in an engineering context. This makes the inclusion of engineering in mathematics and science standards a natural fit. The NAE's *Standards for K-12 engineering education?*[5] has made recommendations for including engineering standards into proposed new national science standards, and the *Next Generation Science Standards*[45], which will be based on the *Frameworks for K-12 Science Education*[4], will include engineering. Despite the fact that engineering standards appeared most often in the Career and Technical Education standards, the inclusion of engineering into the science standards appears to be the most logical placement considering the current status of national standards. The Common Core State Standards in Mathematics do not include engineering and have been adopted by 45 states. However, there is the option of having 15% of mathematics standards be created by states. This portion of the mathematics standards could include engineering, as we found one state only sparingly incorporated engineering in their mathematics standards.

The development of the framework that was described in this paper can further help to guide the future of K-12 engineering education. K-12 engineering education is vital to developing a future generation of engineers and inventors that can provide safety, health, and new technological innovations for the world. The work done for this framework has provided useful information for a revised framework. Future research includes describing the updated framework and applying it to all 50 states' mathematics, science, career and technical education, and information technology standards.

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