AC 2011-1429: NATIONAL SURVEY OF STATES' P-12 ENGINEERING STANDARDS

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National Survey of States' P-12 Engineering Standards

Introduction

In the U.S., the last decade saw a tremendous growth in support for STEM (Science, Technology, Engineering, and Mathematics) education: The Federal Government initiated a series of new and stronger endowed research programs through its National Science Foundation (NSF), teacher education saw new programs to ease the transition of scientists and engineers becoming teachers, and new curricula are experimenting with different ways of strengthening STEM from elementary to high school levels through integrating themes, content, processes, and methods of multiple disciplines [(1)]. A large area of new curricula is engineering-inspired and, in the last several years, the amount of engineering curricula has drastically increased [(2)], with each curriculum providing definitions of engineering through their unique design. When compared to science and mathematics education, pre-college engineering is still in its infancy and still defines its own space within the P-12 system as there are no national engineering standards across K-12 and there is still debate as to whether such standards are even desired. Due to the lack of formal recognition of engineering in K-12, there is no tested, large scale system of teacher preparation.

Recent publications set the stage for further development. In 2009, The US National Academy of Engineering published a report on K-12 Engineering Education, and more recently released an additional report on K-12 Engineering Standards. In the "Engineering in K-12 Education" report, the National Academy of Engineering and the National Research Council declare that no national engineering standards exist in K-12 education [(3)], and the newly released NAE report on engineering standards argues against national stand-alone standards preferring to follow a route of integration of engineering into other academic standards. In this absence of a national standard, several states provide engineering standards or move in such directions providing solution paths that can be informative and insightful for the larger national debate.

The purpose of this study was to provide direction in creating standards for P-12 engineering by compiling and analyzing existing engineering related standards that already exist in state academic standards across the nation. It was designed to answer several questions about existing standards in order to provide direction in future standards design efforts. 1) What states have engineering in their standards? 2) In what subject areas can engineering related standards be found? 3) What types of engineering are conveyed in the existing standards? 4) What are the big ideas of engineering that are present in existing standards?

Background

During the timeframe of this study, the National Academy of Engineering (NAE) commissioned a study and published a report from the Committee on Standards for K-12 Engineering Education (NAE Standards Committee) entitled "Standards for K-12 Engineering Education?" which argues against the creation of national stand alone engineering standards for K-12 [(3)]. The NAE report contradicts other reports [(2; 4; 5)],and ongoing efforts to add engineering to the national science standards framework [(6)], as well as national assessments for science that include engineering and technology applications [(7)], are already in production. The report does, however, offer an opportunity to move the discussion forward – particularly on individual state levels - by integrating recommendations such as the mapping and integration of engineering into science and math standards as well as by determining what the big ideas of engineering are that need to be taught in the P-12 classrooms [(3)]. The report helps this project maintain its importance because the collection of existing standards at the state level can help promote opportunities for integrating engineering into other content areas and assessing current standards helps to develop the big picture of what is taught, and therefore what it is possible to teach, in the schools [4].

The role of standards

Efforts at creating educational standards often face opposition, [8] but many argue that standards drive innovation in education and can be the first step towards implementation of assessments, teacher training, curriculum, and textbooks [9; 3; 10] necessary to transform the ideas that a content area such as engineering offers into effective and meaningful instruction practices.

> "What gets taught in P-12 classrooms is often a function of what gets emphasized in national and state content standards, together with what is assessed on state-mandated achievement tests. Therefore, it is critical to ask what aspects of the "E" in STEM are currently found in major standards documents as well as what may be missing." [2]

In 2008, Brophy et al. reflected the direction of the engineering community when creating the widely cited report, "Advancing Engineering Education in P-12 Classrooms," by outlining a path for further integration of engineering into the science, technology, engineering, and math (STEM) curricula. The report summarized efforts in P-12 engineering being made at the time then and took a look forward to the prospects of the spread of engineering education. In addition to its own call for the creation of standards, the Brophy report discusses efforts by the American Society for Engineering Education (ASEE) at promoting standards-based instruction in P-12 engineering [11], an effort by the NAE to push for design and technology standards [12], the State of Massachusetts's initial development of explicit engineering standards, and reviews of other engineering programs [13].

The NAE standards report comes at a crucial time for stakeholders in engineering education because it coincides with the creation of the national core science standards framework considered to join mathematics and language arts in a nationwide consensus of academic standards which include engineering and technology design [3; 14; 4; 6]. While the NAE Standards Committee proposes a slow cautious approach, such as was taken by the National Council of Teachers of Mathematics that took nearly a decade [15] to create its first set of standards, the current timing of the development of the common core standards in math and language arts soon to go into effect across most of the nation, make it seem logical that science and social studies would be next in line for such a development [3]. It is also critical to note that delays and cautious responses by the engineering community create several scenarios, in which the engineering community loses a large opportunity and, by default, leaves the defining engineering standards in P-12 to other stakeholders. As one piece of evidence shows, the NAE is only marginally represented in the creation of the national science standards, which contain now for the first time several explicitly stated engineering components. Even though standards, like engineering itself [10], are under constant development in "an iterative process of comment, feedback, and revision," [16], it seems timely for the K-12 engineering education community to get on board with the initial science standards development. The NAE Standards Committee, itself, wrote that, "… there is enough agreement about most of the major ideas to suggest that a consensus could be reached through thoughtful, collaborative deliberation, (3 p. 30)".

Achieving a consensus amongst experts on the major ideas of the subject is the first step in creating standards, closely followed by creation of assessments, teacher professional development, curricula and textbooks [2], and does not appear to be as distant a goal as the NAE Standards Committee suggests. This research project could potentially help build consensus by taking on one of the approaches for creating standards recommended by Sneider and Rosen, meaning that through a collection and review of existing standards, such as this, we can "imagine how they might be shaped in their next iteration so that they are perceived by practitioners as essential" [14 p. 2].

Against stand alone engineering standards and for integration of engineering

Rather than establishing stand-alone engineering standards, which would require its own single space in the curricula, the NAE Standards Committee recommends the infusion of engineering into existing standards and integrating engineering concepts into other subjects through mapping. According to the NAE Standards Committee, in the overall conclusion:

> The committee concluded that, although it is theoretically possible to develop standards for K–12 engineering education, it would be extremely difficult to ensure their usefulness and effective implementation. This conclusion is supported by the following findings: (1) there is relatively limited experience with K–12 engineering education in U.S. elementary and secondary schools, (2) there is not at present a critical mass of teachers qualified to deliver engineering instruction, (3) evidence regarding the impact of standards-based educational reforms on student learning in other subjects, such as mathematics and science, is inconclusive, and (4) there are significant barriers to introducing stand-alone standards for an entirely new content area in a curriculum already burdened with learning goals in more established domains of study [3 p. 14].

"Developing standards may be easy; overcoming the barriers related to implementation present the most difficult challenges. Assuming a 'build them and they will come' posture would be a fatal mistake." [17 p. 15] Rodger Bybee, who provided one of the six primary papers referenced by the NAE Standards Committee in its report, has promoted technology standards in the past. However, in his report to the committee that suggests a move towards STEM literacy, he warns of the barriers to implementation of national engineering standards such as, "federal laws (e.g., No Child Left Behind), state standards and assessments, teachers' conceptual understanding and personal beliefs, instructional strategies, budget priorities, parental concerns, college and university teacher preparation programs, teacher unions, and the list goes on." [17 p. 13] His metaphor of school curricula being like an over-filled silo, in which the education community keeps pouring more and more information into the curriculum without ever taking anything out, is directly referenced in the report by the NAE Standards Committee. This idea is supported in the 1997 curriculum study, The Third International Mathematics and Science Study (TIMSS), which found that teachers are overburdened by lengthy standards in too many subjects and that the standards need to help set priorities in order to have an impact [18]. In its 2008 report that advocates creating engineering standards, the Committee on K-12 Engineering Education writes, "individual schools and teachers are faced with accommodating additional content in an already crowded curriculum." [4 p. 4] Another report referenced by the NAE Standards Committee by James Rutherford (2009) indicates that, "Since the end of the second world war, the K-12 curriculum has steadily been adding content and removing little." [19 p. 2]

Bybee, Rutherford and the NAE Standards Committee all propose multi-step approaches to furthering the integration of engineering into school curricula. Bybee (2009) points to creating world-class STEM literacy standards with the most important parts of engineering being expressed in relation to English, math, science, and social studies content. Rutherford (2009) lays out steps that include creating standards that can be integrated into the other subjects using engineering and design contexts, creating an education center for "21st-century curriculum" (p. 2) that ensures an engineering presence in K-12 education, a computer facility to maintain engineering curriculum materials, and design of a process that will monitor and evaluate engineering standards and materials. The NAE Standards Committee's report calls for funding by interested parties to support the development of core engineering ideas and guidelines for instructional materials, research by cognitive scientists to inform the development of the core ideas, and a nationwide survey of formal and informal K-12 engineering programs (2010).

Towards Standards

The report from the NAE Standards Committee (2010) was created using a balanced approach to what committee member, John Chandler, described as, "answering the question: 'What would be the value and feasibility of developing national standards for engineering education in K-12?' [(20)] Despite the overall conclusion of the report and due to the balances approach, it does contain a considerable amount of information to help build an argument for standards that agrees with other research:

> For a subject new to most K–12 classrooms, standards can also make a statement about the importance of that subject for students and for society at large. Thus standards for K–12 engineering education could help create an identity for engineering as a separate and important discipline in the overall curriculum on a par with more established disciplines. (3 p. 19)

Larry G. Richards, Professor of Mechanical and Aerospace Engineering at the University of Virginia, referred to a leader in the Massachusetts standards effort, Ioannis Miaoulis, as an example, when noting people in engineering education need to:

> (1) Increase the understanding of engineering among teachers, students and parents. Help them become aware of the nature of engineering and how it differs from other fields. (2) Capture students' interest early and keep them involved in engineering, science and mathematics. (3) Influence the pre-college curriculum and instructional standards… That means getting involved with local and state educational policy agencies. [(21)]

Not only can integration of engineering into P-12 curricula help students understand engineering and become excited about it [(4)], it can also be "used to engage students in learning, reinforce STEM concepts learned in their academic classes, and also give teachers tools to teach STEM content in a context that provides the "why" to learning." [(22 p. 388)] In their research of engineering design models to use with students, Tate, et al. [(22 p. 380)] also cite reports from the National Science Board in 2007 and the Committee on K-12 Engineering Education in 2009 that show "that engineering may be a positive vehicle to motivate a kindergarten through grade 12 (K-12) student to study [sic] other STEM subjects."

Engineering in the context of math and science

The implication of engineering providing context to math and science principles takes greater importance when considering alternative models. Research shows learners have better understanding of difficult math and science concepts when they create their own models than when given abstract models that do not reflect their everyday world [(23)]. Engineering allows students to "solve basic problems faced in everyday life by employing concepts and models of science, technology, and mathematics." [(24 p. 11; 25)] Abstract models from science and math can be transformed in engineering into physical models that students create to add meaning through "the creative solutions that they generate (in hypothesis space) by analysis, argument, and critique." [(6)]

Engineering "can be both an integrator and contextualizer. That is, K- 12 engineering education can place mathematics, science, and technology in a meaningful, real-world context. [4 p. 25]"

Similarly, engineering can be contextualized by students as it applies in specific engineering and design contexts as well as personal contexts:

> "First, engineering education encourages people to understand engineering in daily life so they can get benefits at work and home, choosing the best products, operating systems correctly, and troubleshooting technical problems when they need. Second, the knowledge of engineering and engineering thinking can increase people's ability to judge and make decisions about national issues related to technology use and development." [24]

Standards Driving Assessment, Curriculum and Teacher Development

From the report by the NAE Standards Committee:

> "Most contemporary theories of education reform suggest that, for standards to have a meaningful impact on student learning, they must be implemented in a way that takes into account the systems nature of education (e.g., AAAS, 1998; NRC, 2002). For example, it is commonly understood that effective standards must be coherently reflected in assessments, curricula, instructional practices, and teacher professional development, [3 p. 30]"

The NAE Standards Committee espoused a counter-intuitive argument in claiming that engineering standards cannot be implemented because assessments, curricula and professional development do not exist due to the newness of the field, "the most serious argument against developing content standards for K–12 engineering education is our limited experience with K–

12 engineering education in elementary and secondary schools". Later, they continued by discounting what has been done in Massachusetts and other states, "Currently there are no content standards, the traditional tool for guiding curriculum development, teacher education, and learning assessment, for engineering. [3 p. 43]" Which, echoed a previous statement, "almost no research has been done, and there is relatively little practical experience to guide decisions about when specific engineering ideas or concepts should be introduced and at what level of complexity [3 p. 19]." These arguments are akin to throwing their hands in the air and saying it cannot be done since it has not been done before. This, as the report itself points out, is not entirely true as the report points toward the benefits of using "core ideas" as "… a resource for improving existing or creating new curricula, conducting teacher professional development, designing assessments, and informing education research. [3 p. 39]"

Of the many experts that have written about standards driving educational reform, NAE Standards Committee member Bybee is among those who have advocated using standards to lead the development of the assessments, curricula, instructional practices and teacher training. In reference to technology standards, he wrote:

> "The power of standards lies in their capacity to change fundamental components of the educational system, which include curriculum programs, instructional practices, and educational policies designed to implement and sustain the changes implied by the standards. Innovations, such as standards, that have direct influence on curriculum, instruction, and assessment have far more potential for achieving higher levels of technological literacy. Standards influence the entire educational system because they are input, but they also define output." [9 p. 27]

Similarly, the NEA report from 2009, *Engineering in K-12 education: Understanding the Status and Improving the Prospects*, provides a comprehensive strategy for implementing engineering in the pre-undergraduate years. "One way to access the technical core is to work toward "coherence" by creating educational systems with standards, curricula, professional development, and student assessments and school leadership that supports the need for change [(10 p. 12)]. The 2009 report also stated, "Broader inclusion of engineering studies in the K–12 classroom also will be influenced by state education standards, which often determine the content of state assessments and, to a lesser extent, curriculum used in the classroom." [(10 p. 163)]

The standards movement, in general, was based on using standards to drive curriculum development, assessments and teacher training. "The fundamental idea of standards-based reform was to establish clear, coherent, and important content as learning outcomes for K–12 education. [(3)] "Standards are an essential part of education reform and policy makers view standards as the guiding force behind state education policies [(26)]. And, in this time of increased accountability, standards-based curriculum and standards-based assessments will drive policies that will "support schools and teachers by providing professional development opportunities, instructional materials, and appropriate resources to enhance their efforts to raise performance levels of their students. [(8)]"

Engineering education content

While the main goal of this project was to collect and analyze the standards that relate to engineering in order to help others create a consensus of what makes up engineering education for P-12, a working definition of engineering was first needed to guide the search through the state standards. Our initial search borrowed from ideas found through literature review. The initial criteria stemmed from the Committee on K-12 Engineering Education 2008 report, which provided the following:

- "Engineering — a process for creating the human-made world, the artifacts and processes that never existed before." (p.9)

  "Most often engineers do not literally construct the artifacts, they provide plans and directions for how the artifacts are to be constructed." (p.9)
- "They also design processes…" (p.9)
- "Engineering Design Process — the iterative process for creation and manipulation of the human-made world. The process combines knowledge and skills from a variety of fields with the application of values and understanding of societal needs to create systems, components, or processes to meet human needs. Initialized by problem definition, followed by clarity of the specifications that the designed product must meet, the open-ended engineering design process optimizes competing needs and constraints, and uses modeling and analysis to drive the creation of new engineered solutions to serve humankind." (p.9)
- "Technology — the artifacts of the human-made world…" (p.9)
- "Technology also includes the knowledge and processes used to create and to operate the artifacts—engineering know-how, manufacturing expertise, various technical skills, and so on—are equally important. An especially important area of knowledge is the engineering design process, of starting with a set of criteria and constraints and working toward a solution—a device, say, or a process—that meets those conditions." (p.9-10)

- "Optimization—the process of determining the best solution to a technical problem, while balancing competing or conflicting factors (constraints). Often, different alternatives will be better in different ways." (p.11)

The report adds that design must contain two of the following aspects: Systematic analysis, Constraints, Modeling, Optimization, and Systems.

Dym, Agogino, Eris, Frey and Leifer, when discussing post-secondary engineering, in *Engineering Design Thinking, Teaching, and Learning* (2005), provide a definition that can be used at all levels of engineering design instruction:

> Engineering design is a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints. This definition promotes engineering design as a thoughtful process that depends on the systematic, intelligent generation of design concepts and the specifications that make it possible to realize these concepts. Design problems reflect the fact that the designer has a client (or customer) who, in turn, has in mind a set of users (or customers) for whose benefit the designed artifact is being developed. The design process is itself a complex cognitive process. [27 p. 104]

In *Towards a Vision for Engineering Education in Science and Mathematics Standards* (2009), Sneider and Rosen provide a list of nine "Big Ideas" that engineering in standards should convey while maintaining a small profile that fits in with the call for narrower and concept-directed standards [15]:

A Vision of Engineering Standards in terms of Big Ideas [14]

Knowledge

1. Engineering design is an approach to solving problems or achieving goals

2. Technology is a fundamental attribute of human culture

3. Science and engineering differ in terms of goals, processes, and products

Skills

4. Designing under constraint

5. Using tools and materials

6. Mathematical reasoning

Habits of Mind

7. Systems thinking

8. Desire to encourage and support effective teamwork

9. Concern for the societal and environmental impacts of technology

Following these definitions of engineering, for the operationalization of this project, we deliberately chose a definition of engineering which encompasses the broader and multi-faceted definitions as provided above.

Methodological Framework

For this study, we chose the methodological framework of a multiple case study, each state representing a case and within its case containing variations depending on the subject area and standard.

Methods of Collection

Science, math, technology, vocational, engineering, and career standards were collected from each state. Research team members pulled standards that relate to engineering and technology design from each standards document using a liberal approach. The liberal approach meant that terminology which was in congruence with the definitions of engineering had to be utilized, yet the standards text did not have to explicitly mention engineering. These key terms: Engineering, Design, Process, Optimization, Modeling, Testing, Properties (of Materials), Prototype, Design Task, Iterative, Technology, Constraints, and Criteria were based on the literature review as being common terms among the main ideas of engineering education and backed by the definitions. Standards that could be related to engineering skills and concepts were identified during the liberal search phase (e.g., collecting data, creating models, sorting materials, etc.).

The collected standards were then rated using a more strict coding system (described below). In the early stages of the coding process, it was decided that two codes would be eliminated due to overlapping of concepts (solving problems in engineering context and improving technologies), and one code was added to differentiate between general design process references and references to specific steps in the design process. A word count was created to identify the most common words and the eighteen most frequent word roots (design, engineer, model, machine, iterat, optimiz, technol, develop, process, system, product, evaluat, material, tool, prototyp, mechanic, construct, manufactur), not including common English words, found in the standards that were identified as engineering, and were used in a Generalized Regular Expression Parser (GREP) search through all of the standards files in order to locate any standards that may have been missed during the initial review. The missed standards were then coded and inserted into their proper location in their state listing.

The first worksheet of the standards database that was created gives an overview of the engineering standards that were found in the survey of the standards. The degree to the amount of engineering and technology design standards is indicated in the first column as either: A) No engineering or technology design standards found; B) States with explicit engineering standards; C) States with engineering in the context of technology design; D) States with some mention of engineering components; and E) States with some mention of engineering in the context of technology design. A brief descriptive identifier is provided to indicate in which area of content the standards were found such as Science, Science and Technology, Math and Career, and Technical Education (Tables 2 and 3). A brief description of the type of standards is given to indicate if the standards include, for example, the engineering design process, engineering applications, or the number of standards (if very few) found. The grade levels mentioned in the standards is also indicated in the chart as well as comments, if any, for each state.

The coding totals are indicated in the right two columns in order to characterize the types of standards found. Design Knowledge & Applications indicates standards that are found to most directly define the design process or to refer to specific steps in the design process or specified applications of such. Related Skills, Systems, and Technology Knowledge refers to standards that discuss engineering and technology design skills that relate to engineering, knowledge of technology such as innovations and the effects of technology on society, and technological systems applications. The numbers, when used in a ratio, can reflect the emphasis of the standards but are not meant to indicate a score or rating of the strength of the standards present.

Seven codes were used in the coding. Design Knowledge and Applications included one code for Design Process Knowledge or Applications and one for Specific Parts of the Design Process. Design Process Knowledge or Applications includes general statements about the use or application of the design process, general definitions of the design process, or single standards that lists all of the steps of the design process. Specific Parts of the Design Process refer to standards involving things such as testing a prototype, identifying constraints and criteria, or brainstorming ideas for a design. Related Skills, Systems and Technology Knowledge consist of codes for: Needs Specific Context to be Engineering; Skills Related to Engineering; Assessing Technology Impact and Innovations; Knowledge of Engineering Field; Incomplete Aspect of Engineering; and Systems Knowledge.

The strict coding was conducted with an emphasis on "doing engineering" or performing an engineering related activity, specifically in an engineering context. Therefore, almost all of the math and science standards were eliminated such as those listed in the initial paragraph discussing the coding: collecting data, creating models, sorting materials, to name a few. Designing a scientific experiment, creating a survey to collect data to display or make predictions from and using proper tools for measurement are other examples of standards that were not counted as engineering unless they were used in an engineering or technology design context.

Modeling is another common example of standards that were not considered as engineering unless in specific contexts. Modeling is part of engineering [(4)]; the modeling mentioned in state math standards lacks specific engineering contextualization. For this reason, instances of mathematical modeling, a part of all states' math standards, are not included in these engineering standards. The Illinois math standards come close to describing contextualized mathematical modeling when saying, "Modeling is the process of choosing and using appropriate mathematics and statistics to analyze empirical situations, to understand them better, and to improve decisions." Another example of contextualized modeling relating to engineering is present in the Illinois math standards document, "Other situations, modeling a delivery route, a production schedule, or a comparison of loan amortizations need more elaborate models that use other tools from the mathematical sciences." However, since this information is provided in the discussion portion of the mathematics standards and is not an actual designated standard itself, it was not included in our database. The standards that deal with mathematical modeling do not stand alone as engineering but the discussion is important to note here as a prime example of how engineering can be integrated into math standards.

Results

The strict coding recognized a total of 1,430 engineering and technology design related standards in 34 states. Of the 25 states found to have the most directly related standards, 15 states have explicit engineering standards and 10 states have standards where engineering is in the context of technology design (Figure 1).

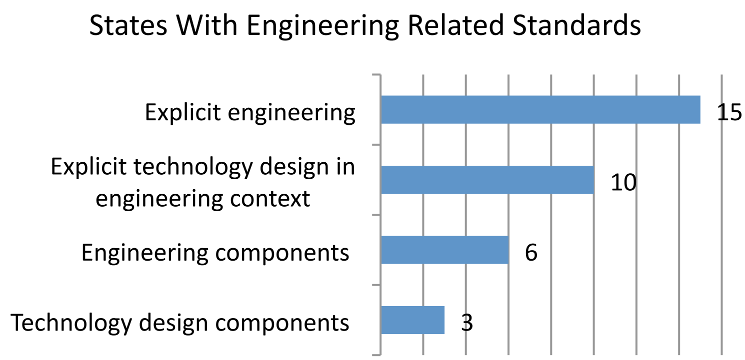

Figure 1

The grouping of the states together by the types of standards found (Table 1) do not imply that the standards are of equal strength or value within each category.

Table 1

How engineering is found	
States with engineering standards	Alabama, California, Connecticut, Georgia, Idaho, Indiana, Maryland, Massachusetts, Minnesota, Mississippi, New York, Ohio, Oregon, Tennessee, Texas
States with engineering in the context of technology design	Colorado, Illinois, Kansas, Maine, Nebraska, New Jersey, South Dakota, Vermont, Washington, Wisconsin.
States with mentioning of engineering components	Hawaii, Michigan, New Hampshire, Pennsylvania, Utah, West Virginia
States with mentioning of technology design components	Alaska, Arizona, South Carolina

Looking at the map of states according to the types of standards found (Figure 2) shows that in most cases, states reflect similar instruction to at least one of their neighboring states.

States With Engineering Related Standards

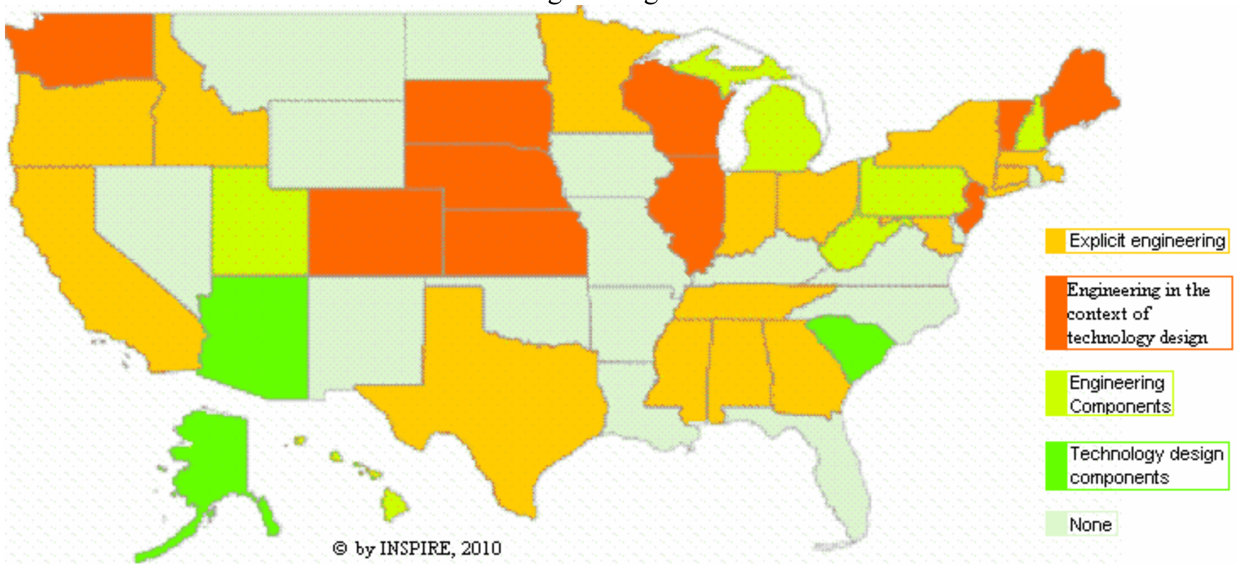

Figure 2

Table 2 shows the list of states that have explicit engineering standards, meaning that the engineering components are explicitly labeled as such.

Table 2

	States with explicit engineering standards				
State	Standard name	How engineering is present	Grades	Design Knowledge & Applications	Related Skills, Systems and Technology Knowledge
Alabama	Technology Education	Engineering design process and applications	HS	6	24
California	Career Tech Content Standards	Engineering design process and applications	HS	30	49
Connecticut	Technology education	Engineering Design components as part of standard	K-12	11	12
Georgia	Career, Technical and Agriculture Education	Individual engineering courses (standards) as part of set of standards	HS	6	14
Idaho	Technology	Engineering design process and applications	K-12	43	3
Indiana	Science	Engineering design process and applications	K-8	35	14

Maryland	Technology education	Engineering design and applications	Gr 6-8	76	14
Massachusetts	Science & Technology/Engineering	Engineering design process and applications	K-12	89	5
Minnesota	Science	Engineering concepts and designs	K-12	13	62
Mississippi	Math (Geometry)	Engineering course in mathematics	HS	5	8
New York	Technology Engineering Design	Engineering concepts as part of the standard	Gr 5-12	71	14
Ohio	Career Tech Content Standards	"Engineering and Science technologies" as part of standard		116	71
Oregon	Science	Engineering design and applications	K-12	30	11
Tennessee	Science	Engineering and technology design process	K-12	46	55
Texas	Career and Technical Education	Engineering design courses	HS	86	15

Table 3 lists the states that have engineering concepts but use a technology design process that is very similar to the engineering design process.

Table 3

	States with engineering in the context of technology design				
State	Standard name	How engineering is present	Grades	Design Knowledge & Applications	Related Skills, Systems and Technology Knowledge
Colorado	STEM	Technology design and engineering concepts	HS	10	17
Illinois	Science	Technology design process and applications	K-12	50	12
Kansas	Science	Technology design process and applications	K-12	12	16
Maine	Science and Technology	Technology design process and applications	K-12	30	0
Nebraska	Science	Technology design process and applications	K-12	18	7
New Jersey	Technology & 21st Century	Technology design	HS	16	3

	Skills				
South Dakota	Technology Education & Educational Technology	Technology design process knowledge mentioned	K-8	17	7
Vermont	Science	Technology design process application	P-12	18	0
Washington	Science	Technology design process explained	2-12th	9	0
Wisconsin	Science, Technology	Technology design process and applications	1-12th	23	6

Of the 25 states with significant engineering design or technological design, 23 specifically mention engineering in context. 10 of these states having engineering that can be found in science standards, 8 in technology standards, 2 in STEM standards, 2 in career and technical standards and 1 in math standards (Table 4 and Figure 3).

Table 4

Subject area where engineering is found (by state)	
Science (10)	Illinois, Indiana, Massachusetts, Minnesota, Nebraska, New York, Oregon, Tennessee, Vermont, Washington,
Technology (8)	Alabama, Connecticut, Idaho, Maryland, New Jersey, Ohio, South Dakota Wisconsin
STEM (2)	Colorado, Texas
Career and Technical (2)	California, Georgia
Math (1)	Mississippi

Figure 3

Explicit engineering design instruction appears to be more prevalent at the high school and middle school level while the technology design instruction is more consistent throughout (Figure 4, Figure 5). 14 states have engineering design in high school (Grades P-12: 7; HS only: 5; Grades 5-12: 2) and 10 states have technology design in high school (Grades P-12: 8; HS only: 2; Grades 5-12: 0) (Figure 4). This finding is not surprising given that technology education standards, which contain engineering elements, have a long history in the upper middle and high school levels.

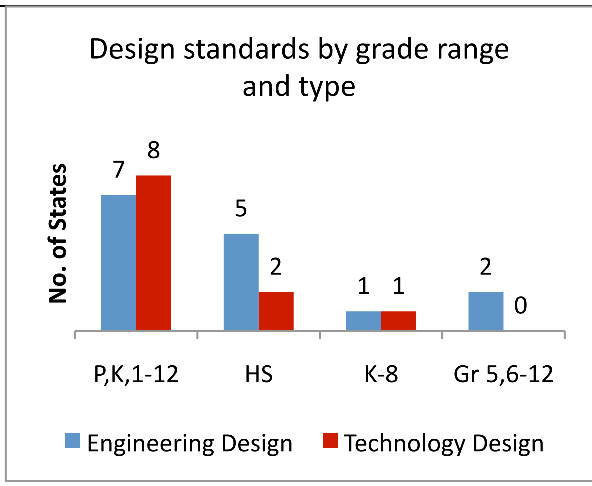

Figure 4

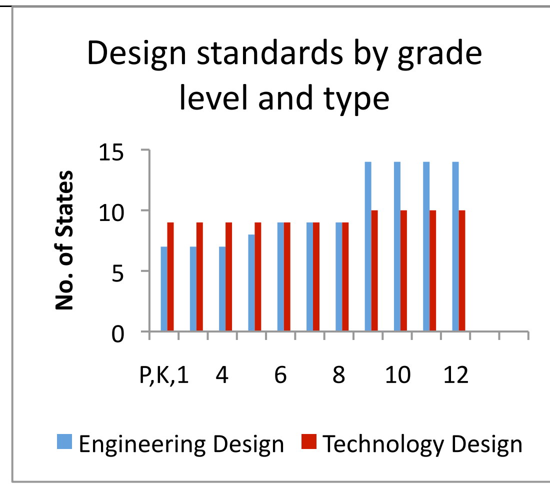

Figure 5

Of the 1,430 engineering and technology design standards, 926 of them were found to focus on the Design Knowledge & Applications, while 504 of them were in Related Skills, Systems and Technology Knowledge (Figure 5).

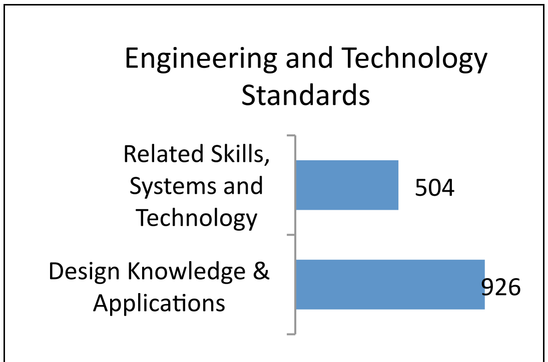

Figure 5

375 standards deal with Design Process Knowledge or Applications and 551 target Specific Parts of the Design Process (Figure 6) that included standards that were directly addressing the design process. Assessing Technology Impact and Innovations was the most common related area with 219 standards (Figure 7) that included content such as engineering related skills, systems knowledge and technology innovations.

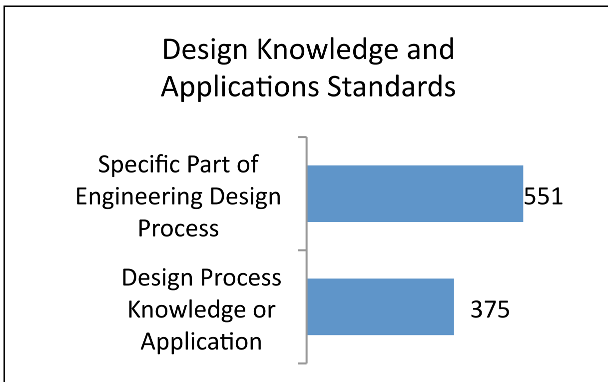

Figure 6- Number of design related standards identified by type category.

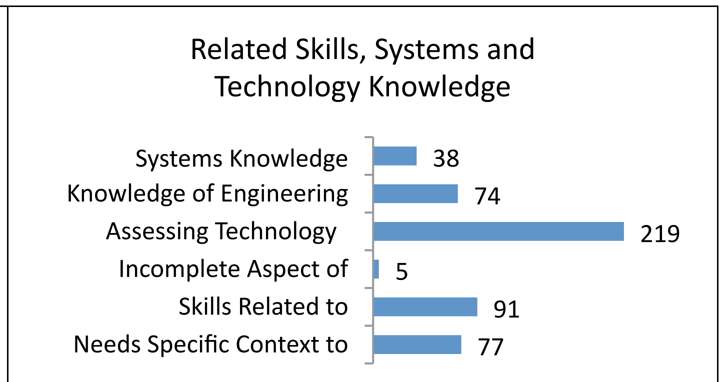

Figure 7 - Number of non-design specific standards identified by type category.

In order to determine what big ideas could be found in the standards, word counts and word clouds, or tag clouds, which are weighted visualizations of word frequencies, were used to identify the most common themes in the engineering standards.(Table 5 and Figure 9).

Count of 100 related words most used in engineering standards

sign	1310	need	181	techniques	89	generate	68	recognize	49
chnology	708	concept	139	research	88	structure	68	step	49
e	683	prototype	136	technical	87	determine	66	change	48
ocess	576	communicate	127	principle	85	environment	64	inspire	47
oblem	533	idea	125	project	84	propose	62	object	47
lution	476	select	123	create	83	possible	61	mechanical	46
stem	375	analysis	118	construct	82	Investigate	60	control	45
entify	319	constraints	118	human	82	define	56	procedures	45
velop	310	draw	115	meet	80	equipment	55	properties	45
plication	291	variety	114	differences	79	impact	55	cost	44
oduce	289	data	112	present	78	expected	54	function	44
derstand	270	demonstrate	112	specifications	78	explore	54	manufacturing	43
aterial	263	work	112	construction	72	creative	53	build	42
lve	245	information	109	document	72	energy	53	question	42
aluate	214	make	109	requirements	72	innovation	52	characteristics	41
odel	214	relationship	108	results	72	modify	52	decision	41
ol	213	criteria	105	measure	70	simple	52	learn	41
plain	210	improve	100	quality	70	team	50	natural	41
st	207	plan	96	safe	70	compare	49	building	39
scribe	186	effect	95	invention	69	example	49	lives/life	39

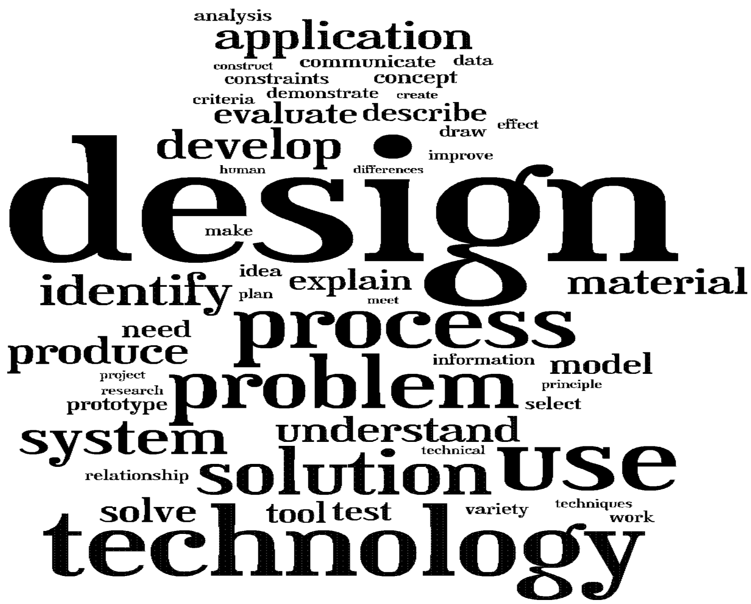

Figure 9

Similarly, the design process standards were used to create a word count for the most common verbs found and then displayed in a word cloud (Figure 10) and a table with examples of standards that use those words (Table 6). The same process was used with the most common engineering related nouns in the design process standards (Figure 11 and Table 7).

Table 3 Most common verbs found in design process standards and examples

Verb	Count	Examples
identify	79	Identify criteria, constraints, problem…
evaluate	76	Evaluate and redesign, modify; Evaluate effectiveness
test	73	Test the design, solution, prototype…
solve	67	Devise a product or process to solve a problem.
describe	42	Describe the reasoning, prior designs…
make	36	Make a model, prototype, product, system, sketches…
select	28	Select appropriate materials, best solution,

		approach...
explain	27	Explain the solution, design factors, etc...
develop	26	Develop plan, layout, design, solution, process…
create	23	Create a solutions, prototype, graphic, product…
communicate	19	Communicate the problem, design, solution…
plan	17	Design, plan and construct; Plan solutions…
propose	15	Propose a solution; Propose designs…
define	13	Define a problem; Define an engineering problem…
brainstorm	12	Brainstorm solutions, design, design questions, plan…
construct	12	Construct a design, prototype, model…
apply	11	Apply criteria, constraints, mathematical models...
improve	11	Improve the solution or model...
build	10	Build a product, system, model…
produce	10	Produce a product, flow charts, system, solutions…

Figure 10 The most common verbs found in the design process standards

Table 4 Most common nouns found in design process standards

Nouns	Count
need	57
criteria	54
constraints	52
model	47
data	42
prototype	42
product	40
results	39
materials	38
ideas	33
tools	24
requirements	13
systems	13
trials	12
analysis	10
modifications	10
procedure	10
specifications	10

Figure 11 Most common nouns found in design process standards

Discussion

Most of the standards rated as engineering, through the strict coding, fall in the science, technology, and vocational areas. The lack of engineering within math standards was surprising; however, a rare exception to the lack of engineering standards in mathematics can be found in the math standards for Mississippi, which include an entire Introduction to Engineering course for secondary students. The course is one of two courses included in the standards that cannot be counted towards meeting the four year math requirement but can be counted towards elective requirements. "This course introduces students to fundamental engineering concepts and encourages the use of creative, innovative, problem-solving skills. Students actively engage in hands-on design projects and participate on engineering teams as often as possible" (Page 80). Rather than discussing the engineering design process, the course description briefly mentions that the state process standards expected from all math courses, "problem solving, communication, reasoning and proof, connections, and representations," (Page 8) "should be incorporated when presenting the content of the curriculum." (P. 80). What are stressed, however, are the content areas of number and operations, algebra, geometry, measurement, and data analysis & probability, each with a short list of math standards to be used in an engineering context:

Algebra

Apply algebraic equations and functions to engineering situations.

a. Write mass and energy balance equations to solve for some unknown value.
b. Find voltage, current, resistance, and solve power in series, parallel, and complex electric circuit theory problems using simultaneous equations generated from Ohm's Law, Kirchhoff's Voltage Law, and Kirchhoff's Current Law (i.e., 3 equations and 3 unknowns).
c. Graph a "Line of Best Fit" from given lab data and determine the degree of linearity (R^2 value), slope of the line, and equation of the line.
d. Determine the BTU requirements and associated utility costs of an engineering operation. (Page 81)

Within the California Technology standards, details are laid out for many career pathways, including the Engineering and Design Industry Sector, which features pathways in Architectural and Structural Engineering; Computer Hardware, Electrical and Networking Engineering;

Engineering Design; Engineering Technology; and Environmental and Natural Science Engineering. The extensive list of standards begins with academic foundation standards in mathematics, social studies, communications/language arts, technology, and career oriented skills such as problem solving, ethics, leadership and technical knowledge. Standards for each pathway are then articulated, and are specific to each field, but include general ideas such as historical perspectives, influences on design, practice in design, and design documentation.

Some states provided additional challenge when coding and reviewing the standards. West Virginia has two standards that were coded as being engineering with one of them being a direct mentioning of engineering: "SC.0.4.3.07: use an appropriate engineering design to solve a problem or complete a task," but had no indicators for what was included in the engineering design process. It was rated as having some mentioning of engineering. Florida was counted as having no engineering standards, but the state recognizes Project Lead the Way courses for credit towards graduation and direct people to the Project Lead the Way standards for specific information. Similarly, The State of North Carolina counts a four year secondary program from Project Lead the Way for credit in the Technology Education program. Middle School students are eligible to participate in an introductory program that features a sequence of four units: Design and Modeling, The Magic of Electrons, The Science of Technology, and Automation and Robots that uses engineering activities to integrate math and science into problem solving.

The Alabama standards provide good examples of standards considered engineering under strict rating versus the liberal rating. Engineering Systems standard nine, "Describe devices used to transfer, convert, change direction, transmit mechanical energy, and overcome friction," involves engineering knowledge or knowledge that an engineer could know. However, standard seven, "Propose solutions to given electrical systems problem statements utilizing fundamental digital electronics, including logic gates, Boolean logic, flip-flops, and other digital components," involves application of engineering knowledge in the context of a problem.

The results of the strict coding differ when compared to results from Kohler et al, (2006) in which a framework, Engineering Education Framework, was constructed and then compared with science standards. That study shows relationships to engineering and technology but found the context of engineering to be weak in 2005 science standards [28]. We are now finding that the context of engineering is increasing.

An interesting aspect of this standards analysis is to compare states' descriptions of engineering, the design processes, and the steps that are included in the design processes. For instance, New York provides a concise description of engineering design: "Engineering design is an iterative process involving modeling and optimization (finding the best solution within given constraints); this process is used to develop technological solutions to problems within given constraints." On the other hand, Ohio's description of engineering design differs with respect to different grade levels, but when assembled, provides a much more detailed description:

> "Design is purposeful, based on requirements, systematic, iterative, creative, and provides solution and alternatives. The design factors and/or processes in the development, application and utilization of technology as a key process in problem-solving. Thinking and procedural steps to create an appropriate design and process skills are required to build a product or system. Engineering design is a subset of the overall design process concerned with the functional aspect of the design. Modeling, testing, evaluating and modifying are used to transform ideas into practical solutions."

Looking at the design processes can also show a large variety in complexity. Standards range from some states only referring to students using the engineering design process with no explanation or listing of steps, some with concise statements about the engineering design process, or others with lengthy multiple-page descriptions covering individual grade levels. Alabama falls on the concise end of the spectrum when describing the steps of design, "Defining the problem, developing and selecting solutions, constructing prototypes testing, evaluating and documenting results, and redesigning as needed." Indiana, much like Idaho, is presented with levels of increasing sophistication (Idaho with four levels and Indiana with three) divided into the following groups: kindergarten to second grade, third grade to fifth grade, and sixth grade to eighth grade.

Indiana's standards are also an example of standards that were reduced in size, but expanded in subject matter, to include technology and engineering by focusing on big ideas in content areas and distinguishing between process standards and content standards. Engineering has been included in both the process (e.g., First Grade: "Identify a need or problem to be solved.") and content standards (e.g., First Grade: "Construct a simple shelter for an animal with natural and human-made materials.") for kindergarten through eighth grade. The design process, specifically labeled as "the engineering design process" for the sixth to eighth grade level is presented as:

- Identify a need or problem to be solved.
- Brainstorm potential solutions.
- Throughout the entire design process, document the design with drawings (including labels) in a portfolio or notebook so that the process can be replicated.
- Select a solution to the need or problem.

- Select the most appropriate materials to develop a solution that will meet the need.
- Create the solution through a prototype.
- Test and evaluate how well the solution meets the goal.
- Evaluate and test the design.
- Present evidence using mathematical representations such as graphs and data tables.
- Communicate the solution (including evidence) using mathematical representations (e.g., graphs, data tables), drawings, or prototypes.
- Redesign to improve the solution based on how well the solution meets the need.

Conclusion

There is much to be learned from examining what has already been done in P-12 engineering education and the efforts of those who have worked towards moving forward with the integration of standards should not be discounted. The engineering in the Massachusetts science standards did not merely appear in 2001, as a large group effort was needed to create the framework (13; 29) that has itself been used for direction from others that have followed (30; 20; 29). Likewise, the effort of implementing the standards in Massachusetts should be lauded as many others working at the state levels can look towards the path traveled by moving the technology and science content towards the science disciplines by showing the relationship between science and engineering, creating assessments and pushing for inclusion in the statewide assessments, including technology/engineering courses towards science requirements for graduation, getting administrators from across the state to get on board, developing curricula and textbooks and working with post-secondary institutions at recognizing students' engineering credits towards admission requirements (29).

The National Educational Goals panel in 1993 put out the call for "world class academic standards" to help students "meet them and compete successfully with students of any country in the world [16 p. 1]" and the National Academy of Engineering and National Research Council put out the call for the United States to resume its position atop the engineering world in 2009 [10]. The Committee on the Engineer of 2020 wrote that the nation's engineering community and schools need to take an active role in improving math, science and engineering in pre-collegiate education to ensure "that all Americans have the opportunity to pursue an engineering education, if they so choose,' and so that our colleges can have "the most highly qualified, best- prepared students [5]." Now is the time for the engineering community to move forward in a unified fashion towards establishing consensus in creating and promoting the big ideas of engineering in every state, across the nation and around the world.

We have found that engineering does exist in state standards across the nation. Whether it is in the context of engineering or technological design, students are learning about engineering in many types of programs in formal and informal settings that are found in academic and vocational contexts. Either figure from this study, 25 states with engineering related standards or 21 that explicitly mention engineering in context, does not match up with the numbers found in the report from the NAE Standards Committee of "no content standards [3 p. 43]" or "a few states [3 p. 40]" that are in place, which shows that pre-college engineering, just like educational standards, are not going away soon [19].

Engineering related standards are found in all shapes and sizes, inconsistent in scope, emphasis, location, subject area, and context. Existing standards are still incoherent on what should be taught when teaching somebody engineering in K-12. Truly, engineering state standards provide rich information and concrete ways in which engineering is already integrated. This study has shown that:

- There are engineering and technology design related standards in 34 states.
- 15 states have strong explicit engineering standards and 10 states have strong standards where engineering is in the context of technology design.
- The majority of standards found relate to design process knowledge or applications, specific parts of the design process and assessing technology impact and innovations.
- There is no time to waste in developing consensus for engineering standards.

The National Governor's Association and the Council of Chief State School Officers wrote about existing standards initiatives, "each state has its own process for developing, adopting, and implementing standards. As a result, what students are expected to learn can vary widely from state to state [(31)]." Those two bodies created the core standards for language arts and mathematics that are soon going into effect across the nation and are one of many groups looking towards core standards in other subjects [(31; 6; 7)] with which the engineering community can partner with so that engineering is presented in the most effective way.

While it is evident that science, technology, math and engineering are tied together [(2)], one important role that the engineering community can take in future standards movements, such as the eventual national core science standards [(3)], is to ensure that the creative aspects of engineering [(32)], or "the inspirational, optimistic aspects of engineering [(22 p. 381)]" can be emphasized when promoting engineering. "Students want their careers to be lucrative, rewarding, limitless, creative, multi-disciplinary, and include travel and group work. [(33)]" Four of the top ten "Best Jobs in America" are in engineering because they offer all of those things (Software Architect #1, Environmental Engineer #5, Civil Engineer #6, and Biomedical Engineer #10) [(34)]. Research shows that children have great misconceptions about engineers as they either have no idea what engineers are. In fact "a large number of teachers erroneously believe that engineers construct buildings [35]." Rather than seeing engineering as creative, rewarding and lucrative, students see engineers as performing manual labor and tasks that require only lower-level thinking [36]. Not only can the engineering community play a role in erasing those misconceptions, but they can help create and implement engineering standards that can lead to students using engineering in their own lives and to better society [24].

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Appendix A

Standards documents referenced:

Alabama

Alabama Content Standards for Mathematics
Alabama Content Standards for Science
Alabama Content Standards for Technology Education

Alaska

Alaska Standards: Content and Performance Standards for Alaska Students for Mathematics
Alaska Standards: Content and Performance Standards for Alaska Students for Science
Alaska Standards: Content and Performance Standards for Alaska Students for Information Technology

Arizona
Science Standard Articulated by Grade Level
Mathematics Standard Articulated by Grade Level
Educational Technology Standard Articulated by Grade Level

Arkansas
Science Curriculum Framework Revision 2005
Mathematics Curriculum Framework Revision 2004 Amended 2006

California
Science Content Standards for CA Public Schools
Mathematics Content Standards for CA Public Schools
Technology Content Standards for CA Public Schools

Colorado
Colorado Academic Standards in Science
Colorado Academic Standards in Mathematics

Connecticut
Content Standards and Expected Performances Core Science for Grades K-12
Connecticut Mathematics Curriculum Framework
Connecticut Career and Technological Curriculum Framework

Delaware
Science Standards
Mathematics Curriculum Framework
A Technical Assistance Guide for Delaware School Districts

Florida
Florida Science Benchmarks
Florida Mathematics Benchmarks

Georgia
Georgia Performance Standards
Georgia Performance Standards

Hawaii
Hawaii Content & Performance Standards Science
Hawaii Content & Performance Standards Mathematics

Hawaii Content & Performance Standards Career and Technological Education

Idaho

Idaho Content Standards Science
Idaho Content Standards with Limits

Illinois

Illinois Learning Standards Science
Illinois Learning Standards Mathematics

Indiana

Indiana's Academic Standards for Science – 2010
Indiana Standards and Resources

Iowa

Iowa Core Curriculum K – 12 Science
Iowa Core Mathematics
Iowa Core Curriculum K-12 21st Century Skills

Kansas

KANSAS Science Education Standards
Kansas Curricular Standards for Mathematics
Kansas Model Curricular Standards for Library Media and Technology

Kentucky

Introduction Core Content for Science Assessment
Core Content for Mathematics Assessment

Louisiana

Science Grade-Level Expectations
Mathematics Grade-Level Expectations

Maine

Science and Technology Section
Mathematics Standards and Performance Indicators

Maryland

State Curriculum - Science
Mathematics State Curriculum
Maryland Technology Education State Curriculum

Massachusetts

Massachusetts Science and Technology/Engineering Curriculum Framework
Mathematics Curriculum Framework

Michigan

Grade Level Content Expectations

Minnesota
Minnesota Academic Standards in Science
Minnesota K-12 Academic Standards in Mathematics

Mississippi
Mississippi Science Framework
Mississippi Mathematics Framework Revised
Mississippi Business and Technology Framework

Missouri
Science Grade Level Expectations
Mathematics Grade- and Course-Level Expectations
Information and Communications Technology Literacy Grade-Level Expectations

Montana
Science Content Standard
Montana K-12 Mathematics Content Standards Framework
Montana K-12 Information Literacy/Library Media Content Standards Framework
Montana Standards for Career and Vocational Education

Nebraska
Nebraska Science Standards Grades K-12
Nebraska Mathematics Standards

Nevada
Science Achievement Indicators Grade Span K-2
Nevada Mathematics Standards
Nevada Computer and Technology Standards

New Hampshire
NH Frameworks for Science Literacy
New Hampshire Curriculum Framework Mathematics
Technology / Engineering Education Curriculum Guide State of New Hampshire Department of Education

New Jersey
Science Standards
Standards for Mathematical Practice
Technology Standards

2009 New Jersey Core Curriculum Content Standards - 21st-Century Life and Careers

New Mexico

New Mexico Science Content Standards, Benchmarks, and Performance Standards
New Mexico Mathematics Content Standards, Benchmarks, and Performance Standards
PRIMARY AND SECONDARY EDUCATION STANDARDS FOR EXCELLENCE CAREER AND TECHNICAL EDUCATION

New York

New York Mathematics, Science, Technology Learning Standards
New York Mathematics, Science, Technology Learning Standards

North Carolina

NC STANDARD COURSE OF STUDY, K-12 FOR SCIENCE
NC STANDARD COURSE OF STUDY FOR MATHEMATICS
NC STANDARD COURSE OF STUDY, K-12 FOR Computer / Technology Skills

North Dakota

North Dakota Science Content and Achievement Standards
North Dakota Mathematics Content and Achievement Standards

Ohio

Engineering and Science Career Field Technical Content Standards Document
Mathematics Academic Content Standards
K-12 Technology

Oklahoma

Priority Academic Student Skills (PASS) SCIENCE
Priority Academic Student Skills (PASS) Mathematics
Priority Academic Student Skills (PASS) Technology Education

Oregon

Standards By Design: Science (2009)
Mathematics Standards

Pennsylvania

Academic Standards for Science and Technology and Engineering Education
Pennsylvania Mathematics Standards

South Carolina

SOUTH CAROLINA SCIENCE ACADEMIC STANDARDS
SOUTH CAROLINA ACADEMIC STANDARDS FOR MATHEMATICS

Industrial Technology Education and (Exploratory) Standards

South Dakota

SOUTH DAKOTA SCIENCE STANDARDS
SOUTH DAKOTA MATHEMATICS STANDARDS
Science, Technology, Environment, and Society Grade Standards, Supporting Skills, and Examples

Tennessee

Tennessee Science Standards 2009-2010 Implementation
Tennessee Mathematics Standards
Computer Technology: Literacy and Usage

Texas

Science Texas Essential Knowledge and Skills (TEKS)
Mathematics Texas Essential Knowledge and Skills (TEKS)
Technology application Texas Essential Knowledge and Skills (TEKS)

Utah

Science Core Curriculum
Mathematics Core Curriculum
Educational Technology Core Curriculum

Vermont

Vermont's Framework of Standards and Learning Opportunities Science
Vermont's Framework of Standards and Learning Opportunities Mathematics
Vermont's Framework of Standards and Learning Opportunities Information Technology

Virginia

Science Standards of Learning for Virginia Public Schools
Mathematics Standards of Learning for Virginia Public Schools
Computer Technology Standards of Learning for Virginia Public Schools

Washington

Washington State Learning Standards Science
Washington State Learning Standards Mathematics
Washington State Learning Standards Educational Technology

West Virginia

21st Century Science K-12 Content Standards and Objectives for West Virginia Schools

Wisconsin

Wisconsin's Model Academic Standards for Science
Common Core State Standards for Mathematics
Wisconsin's Model Academic Standards for Technology Education

Wyoming

WYOMING SCIENCE CONTENT AND PERFORMANCE STANDARDS
WYOMING MATHEMATICS CONTENT AND PERFORMANCE STANDARDS
WYOMING CAREER/VOCATIONAL EDUCATION CONTENT AND PERFORMANCE STANDARDS