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Engineering in the K-12 STEM Standards of the 50 U.S. States: An Analysis of Presence and Extent

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BACKGROUND
Federal initiatives promoting STEM education to bridge the achievement gap and maintain the nation's creative leadership inspired this study investigating engineering content in elementary education standards. The literature review concluded that common national P–12 engineering education standards are beneficial particularly amplified by the common core standards movement.

PURPOSE (HYPOTHESIS)
Compilation and analysis of engineering present in states' academic standards was performed to determine if a consensus on the big ideas of engineering already exists and to organize and present those big ideas so that they can be infused into state or national standards.

DESIGN/METHOD
Extensive examination and broad coding of mathematics, science, technology and vocational/career standards in all 50 states identified instances of engineering content in existing standards. Explicit coding categorized engineering-relevant standards by subject area. Manual and electronic content analysis identified key engineering skills and knowledge in existing standards. Inter-rater reliability verified consistency among five individuals through descriptive statistical measures.

RESULTS
Engineering skills and knowledge were found in 41 states' standards. Most items rated as engineering through strict coding were found in either science or technology and vocational standards. Engineering was found in only one state's math standard. Some states explicitly mentioned engineering standards without any specifics. A consensus of big ideas found in standards is provided in the discussion.

CONCLUSIONS
While engineering standards do exist, uniform or systematically introduced engineering standards are less prevalent. Now is the time to move forward in the formation of national standards based on the state standards identified in this study.

KEYWORDS:
engineering standards, national standard, policy research, state standards

INTRODUCTION

K–12 engineering education is an area of growing national interest, winning attention not only in the engineering community but within the general education community as well. The National Academy of Engineering recently published two books: (1) an inventory of the state of the art in curricula and conceptualizations entitled *Engineering in K–12*

Education: Understanding the Status and Improving the Prospects (2009), and (2) a position statement on national standards in K–12 engineering education entitled *Standards for K–12 Engineering Education?* (2009). Just recently, the National Research Council published a national science standards framework entitled *A Framework for K–12 Science Education: Practices, Crosscutting Concepts and Core Ideas* (2011), containing for the first time substantial engineering components. The National Assessment Governing Board is preparing for the first national assessment of technology and engineering literacy for all K–12 students as outlined in their report *Technology and Engineering Literacy Framework for the 2014 National Assessment of Educational Progress (NAEP)*.

The current inclusion of engineering into the K–12 context has historical predecessors and ancestory in various initiatives originating in numerous parts of the country: Curricula with engineering-inspired components, such as *Engineering is Elementary (EiE)*, *Project Lead the Way (PLTW)* and numerous others (see Brophy, Klein, Portsmore, & Rogers, 2008 for a summary) are widely used across different states. Curriculum providers are now experimenting with various methods of bolstering science, technology, engineering, and mathematics (STEM) education from the elementary to high school levels. These efforts include integration of engineering themes, content, processes, and multidisciplinary methods (Carr & Strobel, 2011). New pre-service teacher education programs are being developed to facilitate transition of scientists and engineers into teaching roles (Grier & Johnston, 2009). Opportunities for in-service teacher professional development support implementation of engineering curriculum in individual schools and classrooms. Additionally, a swell of research in K–12 engineering education is noticeable as federal research programs have made funding available, while new conferences and journals are dedicated to enhancing a broad research agenda.

When it comes to standards, pre-college engineering is still largely undeveloped, particularly as compared to science and mathematics education. Unlike the latter subjects, engineering lacks a defined niche in curricula: there are no national engineering standards at the K–12 level (Committee on K–12 Engineering Education, 2008), and debate continues as to whether such standards are even desired. The NAE report on engineering standards (2010) argues against stand-alone national standards for engineering, instead preferring to integrate engineering content into other existing academic standards. Meanwhile, some states have provided engineering standards or are moving towards providing solutions that can be informative for a larger national debate. The NAE position statement on standards (2010) gives a rudimentary summary of the efforts to develop engineering standards at the state level, but a comprehensive and systematic study of engineering content that already exists in state standards is still needed.

The purpose of this study was to compile and analyze existing engineering-related standards present in state academic standards across the nation, with the ultimate purpose of providing direction in creating shared standards for P–12 engineering education. The research questions of the study were:

1 To what extent is engineering present in current STEM standards in the 50 states in the USA?
2 In what subject areas can engineering-related standards be found?
3 What are the central concepts of engineering that are present in existing standards?

This study is significant to the ongoing standards debate because analysis of the engineering content currently present in K–12 education can inform the debate on national engineering standards, and locating engineering content will indicate existing local pathways and infrastructure available to support teacher preparation for future engineering education, as well as demonstrate possibilities for a systematic integrated framework for engineering in K–12.

BACKGROUND

While this study was conducted, 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, 2010) entitled *Standards for K–12 Engineering Education?* arguing against the creation of national stand-alone engineering standards for K–12. The NAE report minimized efforts being made to add engineering to the national science standards framework (Committee on Conceptual Framework for New Science Education Standards, 2010), as well the development of national assessments for science that include engineering and technology applications (National Assessment Governing Board, 2010). Rather, the NAE report echoed discussions taking place at the state level in recommending the mapping and integration of engineering into science and math standards (Committee on Standards for K–12 Engineering Education, 2010). This report only underlined the significance of the project we were then conducting, as the collection of existing state standards will not only aid in creating national standards, but more specifically sheds ~~led~~ on how engineering can be integrated into other content areas. This study supports development of a broad perspective of what can be taught in schools (Committee on K–12 Engineering Education, 2008).

The Role of Standards

Educational standards, including engineering education standards, have a long history in the United States, with efforts dating back to the 1894 report by the Committee of Ten from the National Education Association (NEA) outlining curricula for secondary schools. The Society for the Promotion of Engineering Education (SPEE) formed in that same year (Grayson, 1980) in response to the rapid growth of post-secondary schools teaching engineering and was an early voice pushing for STEM standards. Inconsistent engineering curricula prior to the 1918 Mann Report and the 1930 Wickenden Report spurred the formation of the Engineers' Council for Professional Development, which established accreditation standards for STEM curricula (Prados, Peterson & Lattuca, 2005).

Despite the nationwide presence of standards and entrance requirements at the college level, pre-collegiate curricula in all areas remained disjointed and driven by local community standards. Attempts through the 1950s and 1960s failed to improve and unify math and science education(Kirst & Bird, 1997). Finally, the standards created by the National Council of Teachers of Mathematics (NCTM) in 1989 have often been cited as the impetus of the modern national standards movement.

The concept behind educational standards has been changing. The NCTM created math standards "to ensure quality, to indicate goals, and to promote change" (Suydam, 1990). Bybee (2000) wrote that standards indicate the inputs and the outputs of education, or the resources and strategies needed to produce desired outcomes. To date, standards have varied from state to state as well as within individual states. Standards have been inconsistent between content areas both in form and function. Some standards documents have addressed knowledge or skills a student should learn; others include things such as curriculum goals, benchmarks, and principles (Kendall & Marzano, 1997). According to many proponents, standards should only focus on outcomes and be used for accountability purposes, while others have seen them as "a vision for what is needed to enable all students to become literate…" in the given subject area (Committee on Understanding the Influence of Standards in K–12 Science, Mathematics, 2002, p.2).

Though the creation of national standards has often provoked critical voices (Weiss, Knapp, Hollweg & Burrill, 2002), standards have been found to drive innovation in education and can engender the implementation of assessments, teacher training, curriculum, and textbooks (Bybee, 2010; Committee on Standards, 2010; National Academy of Engineering, 2009). Standards are necessary for transforming the ideas offered by subjects such as engineering into effective and relevant instructional practices. "What gets taught in P–12 classrooms is often a function of what gets emphasized in national and state content standards" (Brophy, Klein, Portsmore, & Rogers, 2008, p.1).

In their 2008 report on the state of the art in engineering education, Brophy et al. summarized the efforts in P–12 engineering education and analyzed the prospects of integrating engineering into the other STEM disciplines. The report called for the creation of standards and discussed efforts in that direction by several bodies: (1) the American Society for Engineering Education's (ASEE) attempts to promote standards-based instruction in P–12 engineering (Douglas, Iversen, & Kalyandurg, 2004); (2) the NAE attempt to promote design and technology standards (Pearson & Young, 2002); (3) the State of Massachusetts's initial development of explicit engineering standards (Massachusetts Department of Education, 2006); and (4) many existing formal and informal engineering programs.

Since the Brophy et al. report, the urgency of the call for uniform standards has increased. For one thing, the timing of the NAE standards report coincided with creation of the national core science standards framework, which included engineering and technology design (Committee on Standards, 2010; Committee on Conceptual Framework, 2010; Sneider & Rosen, 2009). Meanwhile, the NAE Standards Committee has advocated a slow and cautious approach, such as was taken with the NCTM standards, which took nearly a decade to fully implement (Consortium for Policy Research Education, 1993). The current movement towards core standards in math and language arts also set the stage for timely development of core standards for science and social studies (Committee on Standards, 2010).

The task of defining of engineering standards in P–12 could be taken over by other stakeholders if the engineering community fails to use this opportunity to direct standards development due to delays and excessively cautious responses or a slow approach. Currently, the NAE is only marginally represented in the process of creating the national science standards, which for the first time contain several explicitly stated engineering components.

Now is the ideal time for the K–12 engineering education community to join the science standards development process. Reaching consensus amongst experts on the major tenets of engineering is the first step in creation of standards. Once this consensus is reached, the creation of assessments, teacher professional development, curricula, and textbooks [illegible] soon follow (Brophy, et al., 2008). 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" (Committee on Standards, 2010, p.30). Engineering, it may be argued, is under constant development in "an iterative process of comment, feedback, and revision" (National Education Goals Panel, 1993)—but so are standards (National Academey of Engineering, 2009). For the engineering education community to hang back from this process would surely be to drastically impoverish it.

Opposition to Stand-alone Engineering Standards and the Argument for Integration

Rather than establishing stand-alone engineering standards, which would require a designated space for engineering in curricula, the NAE Standards Committee recommended infusion of engineering into existing standards, that is, integration of engineering with other subjects through concept mapping. The NAE Standards Committee came to this argument based on several findings: (1) there is little experience with K–12 engineering education in U.S. elementary and secondary schools, (2) there is a lack of teachers qualified to teach engineering, (3) the evidence of the impact of standards on other subjects is inconclusive, and (4) significant barriers to introducing stand-alone standards for a new content area exist. These findings led the committee to the conclusion 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" (Committee on K–12 Engineering Education, 2008, p.14).

Zeroing in on the challenge, Rodger Bybee (2009) stated, "developing standards may be easy; overcoming the barriers related to implementation presents the most difficult challenges. Assuming a 'build them and they will come' posture would be a fatal mistake" (p. 15). Bybee, the author of one of the six papers referenced by the NAE Standards Committee in its report, has been a proponent of technology standards in the past. However, in the report to the committee that suggested a move towards STEM literacy, he advised of the potential obstacles to the application of national engineering standards, including "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" (Bybee, 2009, p.13).

Bybee's (2009) metaphor of school curricula as an over-filled silo to which new material is continually added echoed the 1997 curriculum study The Third International Mathematics and Science Study (TIMSS), which found that teachers were overwhelmed by extensive standards in too many subjects and that the standards must be prioritized if they are to be effective (Beatty, 1997). In its 2008 report advocating the creation of engineering standards, the Committee on K–12 Engineering Education stated, "individual schools and teachers are faced with accommodating additional content in an already crowded curriculum" (Committee on K–12 Engineering Education, 2008, p. 4). The NAE Standards Committee referenced another report, by James Rutherford (2009), which indicated that, "Since the end of the second world war, the K–12 curriculum has steadily been adding content and removing little" (p. 2).

Bybee, Rutherford, and the NAE Standards Committee each suggested multi-step processes to better integrate engineering into school curricula. Bybee (2009) proposed the creation of world-class STEM literacy standards that would integrate engineering into an overall STEM curriculum. Rutherford (2009) outlined a course of action that included infusing engineering and design contexts into all subjects and creating an education center for "21st-century curriculum" (p. 2) that maintains a national database of engineering curricula that have been evaluated. Further, the NAE Standards Committee called for funding of curriculum design, cognitive research, and analysis of existing K–12 engineering programs (2010).

Towards Stand-alone Engineering Standards

NAE Standards Committee member John Chandler described creation of the most recent report as using a balanced approach and "answering the question: 'What would be the value and feasibility of developing national standards for engineering education in K–12?" (Pearson, Chandler, Diefes-Dux, Hanson, & Kelly, 2010, August).

The balanced approach allows for a substantial amount of information that, unlike the fears expressed earlier, actually helps build an argument for standards in agreement with other research. According to the committee (2010), "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" (2010, p.19).

The work of Ioannis Miaoulis, a leader in the Massachusetts standards movement was cited by Larry Richards as an example of what people in engineering education should do. Richards discussed the success in Massachusetts of increasing engineering awareness and building early interest by "Influencing the pre-college curriculum and instructional standards… That means getting involved with local and state educational policy agencies" (Richards, 2007, p.1).

To date, Massachusetts and the International Technology and Engineering Educators Association (ITEEA) have led the field of standards design for K–12 engineering. Massachusetts, whose guiding principles in the current science standards call for technology and engineering education to fill at least one-quarter of science instruction in elementary school, first announced engineering standards in 2001. The Massachusetts standards span engineering and technology topics from material properties and use of primitive tools through sophisticated design problems and knowledge of such evolving technologies as bioengineering and thermal systems (Massachusetts Department of Education, 2006). The ITEEA published *Technology for All Americans* in 1996, a book outlining the future of technology education. It included a call for standards as well as an understanding of engineering concepts and design, a call answered in the ITEEA original publication of *Standards for Technological Literacy* in the year 2000 (Center for the Study of Technology, 2007).

Through P–12 engineering education, students come to understand engineering and get excited about it (Committee on K–12 Engineering Education, 2008). Engineering can 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" (Tate, Chandler, Fontenot, & Talkmitt, 2010, p. 388). In their research on engineering design models, Tate et al. (2010) cited reports from the National Science Board in 2007 and the Committee on K–12 Engineering Education in 2009 that showed "that engineering may be a positive vehicle to motivate a kindergarten through grade 12 (K–12) student to study other STEM subjects."

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

> 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. (Chae, Purzer, & Cardella, 2010)

Studies indicate that learners better comprehend difficult math and science concepts when creating their own models than when given abstract models that are unrelated to their everyday world (Linn, diSessa, Pea, & Songer, 1994). Engineering provides students with an opportunity to "solve basic problems faced in everyday life by employing concepts and models of science, technology, and mathematics" (Chae, Purzer & Cardella, 2010, p. 11; Chandler, Fontenot & Tate, 2011). Complex scientific and mathematical concepts can be simplified through engineering into tangible models that students themselves construct through "the creative solutions that they generate (in hypothesis space) by analysis, argument, and critique" (Committee on Conceptual Framework, 2010). 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" (Committee on K–12 Engineering Education, 2008, p. 25).

Standards Driving Assessment, Curriculum and Teacher Development

Standards, of course, do not do educational work in a vacuum. As the report by the NAE Standards Committee explains:

> 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. (Committee on Standards for K–12 Engineering Education, 2010, p. 30)

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 needed to make engineering a strong feature of elementary education. 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." He added, "Standards influence the entire educational system because they are input, but they also define output" (Bybee, 2000, p.27).

The NAE report, *Engineering in K–12* ~~from 2009~~ declared standards, curricula, professional development, student assessments, and supportive school leadership as the imperatives for K–12 engineering (p.12). The 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" (p.163). The report suggests using "core ideas," also known as big ideas as "… a resource for improving existing or creating new curricula, conducting teacher professional development, designing assessments, and informing education research" (Committee on Standards, 2010, p.39). Identifying some of these big ideas, then, is a first step towards creating standards that when properly implemented can have a domino effect, driving and providing a coherent framework for the implementation of educational improvements.

In this time of increased accountability, standards-based curricula 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" (Weiss, Knapp, Hollweg, & Burrill, 2002).

METHODOLOGY

An Operational Definition of Engineering

In order to survey the state standards, preliminary definitions of engineering content needed to be established through literature review. The 2009 NAE report, *Engineering in K–12* provided initial direction:

- Engineering—a process for creating the human-made world, the artifacts and processes that never existed before" (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).
- Optimization—the process of determining the best solution to a technical problem, while balancing competing or conflicting factors (constraints)" (p.11).
- 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), provided 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" (2005, p. 104).

Sneider and Rosen provide a list of nine "Big Ideas" that engineering in standards should convey in *Towards a Vision for Engineering Education in Science and Mathematics Standards* (2009):

A Vision of Engineering Standards in terms of Big Ideas

Knowledge

- Engineering design is an approach to solving problems or achieving goals.
- Technology is a fundamental attribute of human culture.
- Science and engineering differ in terms of goals, processes, and products.

Skills

- Designing under constraint.
- Using tools and materials.
- Mathematical reasoning.

Habits of Mind

- Systems thinking.
- Desire to encourage and support effective teamwork.
- Concern for the societal and environmental impacts of technology.

For the operationalization of this project, we deliberately chose definitions which encompass the broad and multi-faceted concepts: *Engineering is* iterative design and the optimization of materials and technologies to meet needs as defined by criteria under given constraints. *Engineers use* systematic processes, mathematical tools and scientific knowledge to develop, model, analyze and improve solutions to problems. *Engineering design processes are* dynamic and include phases of problem definition, problem solving, testing and iteration.

Methodological Framework

All science, math, technology, vocational, career and engineering standards from each state were compiled and analyzed, with each standards document analyzed as a separate case of a Multiple Comparative Case Study (Yin, 2009). Content analysis of the standards used broad definitions of engineering content and skills (Patton, 2002; Schutz, 1958). Skills necessary for engineering, such as collecting data, creating models and conducting material investigations, were considered engineering regardless of the context they were presented in.

Initial content analysis, open coding and axial coding were performed by a doctoral student in education with expertise in elementary education and engineering education teacher professional development, and by two undergraduate engineering students with experience in engineering education teacher professional development.

Methods of Data Collection

To ensure maximum variation, data acquisition used a purposeful selection of all standards from groups of subject areas meeting the lenient criterion of being related to the application of engineering, including skills and content used in engineering, for example modeling and gravity. A random sampling of other content area standards such as language arts and health was performed to verify that they did not contain engineering-related standards. Science, math, technology, vocational, career and engineering content standards that were current as of December 20, 2010 were obtained through the websites of state departments of education and via e-mail from the departments (172 documents). Another search of standards documents and a review of legislative reports and primary news outlets were conducted to include revised documents as of July 30, 2011. Twelve documents were replaced and rating adjustments were made. Additional categories were added for analysis of the standards to account for state standards that directly refer to ITEEA and *Project Lead the Way* (a high school engineering curriculum) or are predominantly borrowing from them.

Methods of Data Analysis

The analysis of the standards consisted of multiple phases of coding and rating that were repeated. The authors performed a content analysis on standards documents from ITEEA, Massachusetts and Indiana prior to lenient open coding, axial coding, and strict rating by multiple individuals (Figure 1). These standards documents were

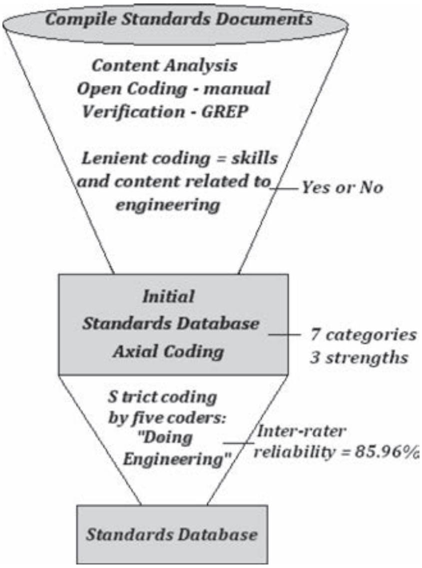

FIGURE 1. Data collection and analysis. Compiled standards underwent content analysis to determine coding scheme prior to two rounds of coding in which inter-rater reliability was established.

selected because they offer a wide representation of specifically stated engineering standards and represent an evolution of engineering content from early concepts to newly created standards, each borrowing from the previous. The ITEEA standards have moved from specific use in technology coursework to a middle ground between technology and science. The Massachusetts engineering standards are firmly situated in technology and science. Indiana's engineering-related standards are found in the standards for science.

Content analysis was conducted using line-by-line analysis of standards documents. The operational definitions from the above literature review and terminology from the content analysis guided the initial open coding of the standards documents. Key terms used in the individual document search, in addition to the definitions in the above section, were: constraints, criteria, design, engineer, iterate, material, model, optimization, process, properties, prototype, technology, and test. Raters were not constrained by the terms and definitions during this lenient round of coding, rather the key terms and general definitions served as guides to increase consistency within a wide, inclusive focus. All standards rated as related to engineering were compiled into a database.

The unit of analysis during all phases of coding was the phrase. An example from the eighth grade New Jersey technology standards is: "8.2.2.B.1: Brainstorm and devise a plan to repair a broken toy or tool using the design process." Another example comes from fifth to eighth grade New York science standards: "Key Idea 1: 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." Additionally, the thirteen individual sub-statements of that standard were assessed as individual units, for example, "T1.1: Identify needs and opportunities for technical solutions from an investigation of situations of general of social interest."

All standards rated as "yes" were compiled into a database before Generalized Regular Expression Parser (GREP) software searched all of the initial standards documents to verify that standards were not overlooked. The GREP software identified key terms and roots based on word counts from the standards already coded. The additional terms/roots identified were: construct, develop, evaluate, machine, manufacture, mechanical, product, system and tool. These were added to the terms listed above for a new GREP search of all standards. Results of the GREP searches (97,094 items) were compared with the database and overlooked standards were coded and added if meeting the lenient criteria. This verification process increased the size of the database by 51 items for a total of 1472 items.

Axial coding determined eight categories for types of standards and three ratings for strength that the authors used with each. Data, the standards statement phrases, were coded in the "strict coding" stage by five researchers (the three initial coders and two undergraduate students from education and engineering) using the following two primary categories: (A) Design Process Knowledge & Applications standards, or (B) Related Skills, Systems & Technology Knowledge standards. Items that fit the narrow-focus criteria of "doing engineering," or direct application went into (A) Design Process Knowledge or Applications and could fall into one of two subcategories: (A-1) Design Process Knowledge or Applications, or (A-2) Specific Parts of the Design Process. Within the related areas category, standards could fall within one of six subcategories: (B-1) In Context of Engineering, (B-2) Direct Engineering Skills, (B-3) Assessing the Impact of Technology and Innovation, (B-4) Knowledge of Engineering Fields, (B-5) Incomplete Aspect of Engineering, and (B-6) Systems Knowledge. Strength was measured on a three-point scale (0, 1, and 2) ranging from not meeting the criteria of being "related to engineering" (0), to related to engineering (1), to content or skills directly applicable to engineering, and presented in the context of engineering or problem solving (2).

The coefficient of intercoder agreement was calculated for the final coding using Holsti's method, or percentage agreement, modified to calculate the agreement to coders' majority agreement (Neuendorf, 2002). Traditionally, this method is seen as overlooking the possibility of chance agreement. However, since all five coders coded every item for a total of eight categories, the effect of chance on the overall reliability is diminished. The coders were in agreement 85.96% of the time, with 11,953 agreements and 1,952 disagreements. There were 42 standards phrases for which a majority was not reached as to the specific type of standard but the top two options were agreed upon. Majority was reached on all strength ratings.

RESULTS

Final coding identified 41 states (Table 1) that have engineering content in their educational standards. Five of these states were found to have only minor or weak references to engineering and technology design components.

Of the 36 states found to have a strong presence of engineering (Figure 2), 11 have their own explicit engineering standards and six have standards that present engineering in the context of technology design. Engineering standards directly borrowed or slightly

TABLE 1
How Engineering is Found in Standards (Grade Levels: MS = Middle School, HS = High School)

California (HS), Connecticut (K–12), Georgia (HS), Indiana (K–12), Massachusetts (K–12), Minnesota (K–12), Mississippi (HS), New York (MS, HS), Oregon (K–12), Tennessee (K–12), Texas (HS)	states with explicit engineering standards
Alabama (HS), Colorado (HS), Delaware (MS, HS), Hawaii (K–12), Idaho (K–12), Illinois (K–12), Kansas (K–12), Maryland (K–12), Missouri (K–12), New Hampshire (K–12), New Jersey (HS), North Carolina (HS), Ohio (K–12), Pennsylvania (HS), Rhode Island (K–12)	states with explicit engineering/ITEEA
Florida (MS, HS), Iowa (MS, HS), North Dakota (MS, HS), Utah (MS, HS)	states with explicit engineering/PLTW
Maine (K–12), Nebraska (K–12), South Dakota (K-5, MS), Vermont (K–12), Washington (K–12), Wisconsin (K–12)	states with engineering in the context of technology design
Alaska (MS, HS), Arizona (K–12), South Carolina (HS)	states with mention of technology design components (large variance; often very weak)
Michigan (HS), West Virginia (MS)	states with mention of engineering components (large variance; often very weak)

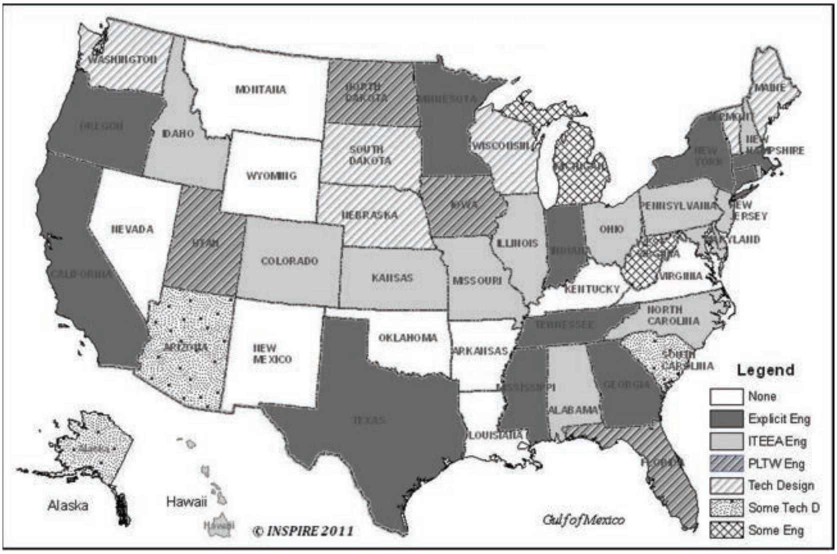

FIGURE 2. Engineering in Standards by Type. None = None found; Explicit Eng = Standards explicitly identified as engineering; ITEEA Eng = State uses ITEEA standards directly; PLTW Eng = State uses PLTW standards directly; Tech Design = Engineering is taught as technology design; Some Tech D = Standards briefly reference or mention engineering in the form of technology design; Some Eng = Standards briefly reference or mention engineering or engineering design.

modified from the *Standards for Technological Literacy* from ITEEA accounted for 15 of the states, while 4 states were found to use explicit engineering standards from the *Project Lead the Way* curriculum.

Of the 36 states identified with strong engineering design or technological design (states with minor or weak mention omitted) in their standards, 12 have engineering content that can be found in science standards, 8 in technology standards, 5 in engineering and technology standards, 2 in STEM standards, 8 in career and vocational standards and 1 in math standards (Table 3 and Figure 4). Of the 12 states with engineering found in science standards, 10 are states that have their own, independent standards.

The majority of standards, 1,472, were categorized as either Design Process Knowledge & Applications standards, or Related Skills, Systems & Technology Knowledge standards. (The 42 standards that were not labeled in a specific subcategory due to lack of majority included 26 Design Standards and 16 Related Standards; these are omitted from these numbers and from Figures 5 and 6.) When divided into the two primary rating categories, 926 standards covered Design Process Knowledge & Applications, while 504 of the standards covered Related Skills, Systems & Technology Knowledge. Within the Design Process Knowledge & Applications category, the Specific Parts of the Design Process (Figure 5) subcategory accounted for 551 of the standards and the general Design Process Knowledge or Applications accounted for 375 of the standards.

TABLE 2
Standard Types by Grade Level

	K–5	Middle School	High School	K–12
States with explicit engineering standards	6	7	11	6
States with explicit engineering/ ITEEA	9	10	15	9
States with explicit engineering/PLTW	0	4	4	0
States with engineering in the context of technology design	6	6	5	5
States with mentioning of technology design components (large variance; often very weak)	1	2	3	1
States with mentioning of engineering components (large variance; often very weak)	0	1	1	0

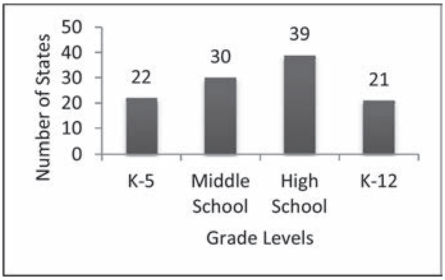

FIGURE 3. Grade levels where engineering or technology design is present.

TABLE 3
Subject Area Where Engineering Content is Found (By State)

Science (12)	Illinois, Indiana, Kansas, Massachusetts, Maine, Minnesota, Nebraska, New York, Oregon, Tennessee, Vermont, Washington
Technology (8)	Alabama, Connecticut, Idaho, Maryland, New Jersey, North Dakota, South Dakota, Wisconsin
Engineering and Technology (5)	Delaware, Missouri, New Hampshire, Rhode Island, Utah
STEM (2)	Colorado, Pennsylvania
Career and Vocational (8)	California, Florida, Georgia, Hawaii, Iowa, North Carolina, Ohio, Texas
Math (1)	Mississippi

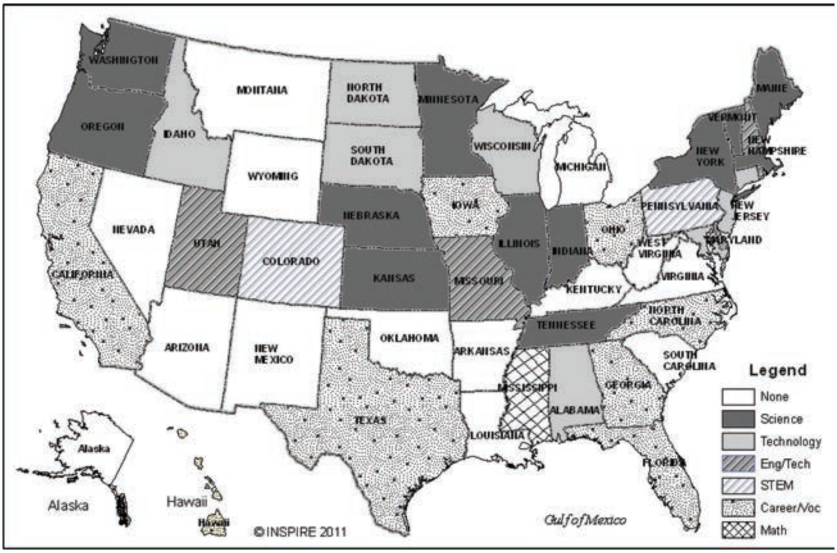

FIGURE 4. Engineering in standards by content area. Engineering is identified in content area standards, as labeled by states.

Figure 6 shows the engineering standards beyond those categorized as design-specific. Assessing the Impact of Technology and Innovations was the most common related area (219 standards) identified. The category of skills that count when presented In the Context of Engineering (but are not necessarily engineering-relevant otherwise) came in second (91 standards).

Grade level bands show that engineering is present in 39 states at the high school level, 30 states at the middle school level, and 22 states at the K-5 level. Twenty-one states include engineering in their standards throughout K–12 (Figure 3).

Table 2 reflects the breakdown into types of standards by grades. States in the K–12 column are also included in the numbers in the other three columns. Therefore, explicit engineering

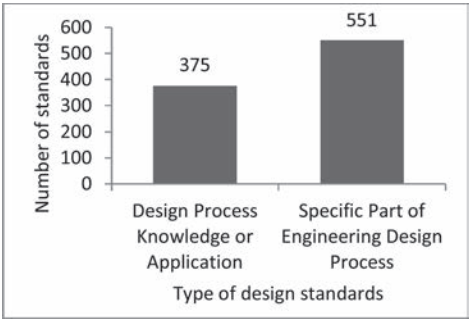

FIGURE 5. Design standards by type. Comparison of coded design standards (926) by focus.

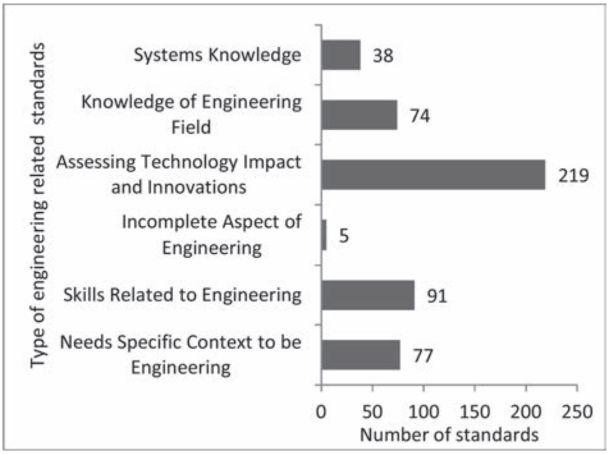

FIGURE 6. Engineering related standards (not design) by type. Standards identified as engineering other than those directly relating to a design process.

standards (independent of ITEEA and PLTW) can be found at the high school level in 11 states, 6 of which also teach engineering in K–Middle School. Explicit engineering standards are more often found at the high school level, while technology design instruction is more consistent throughout the grade levels (Table 2).

While the authors coded the standards individually as phrases, a word analysis was also deemed helpful in locating and portraying the big ideas of engineering that were present. Thus, word counts and word clouds were created to represent the conceptual content of the standards identified as relevant to teaching engineering. Table 4 shows the 80 words that are most common in the engineering standards (with common English terms such as “the,” etc. removed) and the frequency of their inclusion. The word cloud in Figure 7 represents this data in a way that makes the big ideas instantly accessible.

Similarly, the design process standards were analyzed to create a word count for the most common verbs found in them (Table 5 and Figure 8), and then the most common nouns (Table 6 and Figure 9). These word counts help quantify the activities most emphasized in the standards.

TABLE 4
Big Idea Words: Word Count of 80 Most Used Engineering-Related Words Found in Standards

Word	#	Word	#	Word	#	Word	#
design	1310	need	181	techniques	89	generate	68
technology	708	concept	139	research	88	structure	68
use	683	prototype	136	technical	87	determine	66
process	576	communicate	127	principle	85	environment	64
problem	533	idea	125	project	84	propose	62
solution	476	select	123	create	83	possible	61
system	375	analysis	118	construct	82	Investigate	60
identify	319	constraints	118	human	82	define	56
develop	310	draw	115	meet	80	equipment	55
application	291	variety	114	differences	79	impact	55
produce	289	data	112	present	78	expected	54
understand	270	demonstrate	112	specifications	78	explore	54
material	263	work	112	construction	72	creative	53
solve	245	information	109	document	72	energy	53
evaluate	214	make	109	requirements	72	innovation	52
model	214	relationship	108	results	72	modify	52
tool	213	criteria	105	measure	70	simple	52
Explain	210	improve	100	quality	70	team	50
Test	207	plan	96	safe	70	compare	49
Describe	186	effect	95	invention	69	example	49

FIGURE 7. Big Ideas Word Cloud: visual representation of the big ideas conveyed in standards identified as engineering.

TABLE 5
Word Count of Most Found Verbs in Design Standards

Verb	#	Verb	#	Verb	#
identify	79	explain	27	brainstorm	12
evaluate	76	develop	26	construct	12
test	73	create	23	apply	11
solve	67	communicate	19	improve	11
describe	42	plan	17	build	10
make	36	propose	15	produce	10
select	28	define	13		

FIGURE 8. Verbs in design standards word Cloud. Visual representation of the activities emphasized in design process standards.

TABLE 6
Word Count of Most Found Nouns in Design Standards

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

Figure 9. Nouns in design standards word cloud. Visual representation of the objects and processes emphasized in design process standards.

DISCUSSION

A primary goal of this cross-state standards analysis was to discover what big ideas about engineering are currently being taught in K–12 education. The content analysis and coding in this study showed a strong presence of much content that relates to engineering: systems knowledge; engineering applications; types of engineering; assessments of technology and of the impact of technology, innovation, and iteration; engineering-based applications of science and math concepts and skills; and the engineering design process.

In these compiled standards, we found an inclusive consensus on the "big ideas," or what "doing engineering" consists of:

- Identifying criteria, constraints, and problems
- Evaluating, redesigning and modifying products and models
- Evaluating effectiveness of solutions
- Devising a product or process to solve a problem
- Describing the reasoning of designs and solutions
- Making models, prototypes, and sketches
- Designing products and systems
- Selecting appropriate materials, best solutions or effective approaches
- Explaining the solution and design factors
- Developing plans, layouts, designs, solutions, and processes
- Creating solutions, prototypes, and graphics
- Communicating the problem, design, or solution
- Proposing solutions and designs
- Defining problems
- Brainstorming solutions, designs, design questions, and plans
- Constructing designs, prototypes, and models
- Applying criteria, constraints, and mathematical models
- Improving solutions or models
- Producing flow charts, system plans, solution designs, blue prints, and production procedures

Compare the operational definitions used in the analysis of the standards to these findings, and it is abundantly clear that engineering is present in state standards and in curricula across the nation. Engineering has a presence to varying extents in the standards of 41 states. The prevalence of engineering at the secondary levels (39 states present it in high school and 30 in middle school) is not surprising since technology education has been integrated at the high school level in technical and vocational curricula since the early 1990~~'~~s (Dugger, 2010) and has long utilized engineering concepts and terminology. The evolution of technology design to include engineering design over the first decade of the new millennium is reflected by the addition of the second "E," for engineering, in ITEEA's name (ITEEA, 2010).

While almost half (19) of the 41 states with engineering-related standards draw on the ITEEA and PLTW standards, the ways in which states utilize these organizations' standards vary widely. Some states, such as New Jersey, have adopted the ITEEA standards as their own. Others, like Missouri, have integrated certain ITEEA standards into their standards. The resulting standards, like those of states with independently conceived standards, include goals for students' technological understanding, problem solving abilities, systems thinking, and other engineering related skills.

The fact that only 12 states integrate engineering into science curricula and only one into math points to a need for an emphasis on the academic nature of engineering. The move towards STEM integration can borrow from Mississippi's math standards, which include an entire Introduction to Engineering course for secondary students. These standards integrate math content such as numbers and operations, algebra, geometry, measurement, ~~and~~ data analysis and probability into problem solving using engineering skills and concepts.

Almost all state math standards refer to skills such as collecting data, creating mathematical models, use of measurement tools, and manipulation of geometric shapes that can be utilized in engineering-context problem solving. Since modeling is an integral part of engineering (Committee on K–12 Engineering Education, 2008), related standards were noted in the initial coding, yet omitted during the strict coding because they lacked the context of engineering.

Use of models in science standards is another common example of content meeting the criteria of the initial coding yet lacking the context needed in the final coding. The topics of materials sorting, scientific experiment design, designing and implementing surveys from which to make predictions or represent data, and tools of measurement are universal in state standards but only met the criteria of the final coding if present in the context of engineering problem solving. Illinois does refer to the use of models for improving systems, which approaches presenting the topic of modeling in an engineering context. However, the relevant statement ("modeling a delivery route, a production schedule, or a comparison of loan amortizations needs more elaborate models that use other tools from the mathematical sciences") was not an actual standard but was found in a discussion portion of the standards document, so this standard was not included in the database. Nonetheless, it illustrates one of many ways that a big idea from engineering can be mapped onto other subjects.

Alabama Engineering Systems standard nine, "Describe devices used to transfer, convert, and change direction, transmit mechanical energy, and overcome friction," is a specific example of engineering-related content meeting the criteria of the initial coding but failing strict coding because it would lie in the content area of physics since no direct application of the knowledge is conveyed. 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 and therefore meets the criteria of the final coding.

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, as well as career-oriented skills such as problem solving, ethics, leadership and technical knowledge. Standards specific to each pathway are then articulated, but while these are customized, each set of standards includes some general ideas such as historical perspectives on the career, influences on design, practice in design, and design documentation. This shared groundwork is another place to look for big ideas about engineering that can be emphasized early on in education.

California's extensive technology standards are an example of one way to integrate engineering. Standards for each technology career strand, including several fields of engineering, list content connections to science, mathematics, social studies, and communications and language arts standards. Skills such as problem solving, ethics, and leadership as well technical content knowledge to apply in context are included.

Looking at the composition of the standards by breaking them down into specific categories such as design knowledge, design process, and related knowledge aids in finding opportunities for the integration of engineering into other content areas. Systems knowledge can be incorporated into science and technology. Assessing technology standards includes understanding innovation, the evolution of technology and the impacts of technology, goals which can be integrated into social studies and language arts curricula.

The greatest richness and variety of standards content can be found in those states with their own unique standards. Definitions of engineering and descriptions of and references to design processes are rich sites for comparative content analysis. 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." Ohio's standards provide a much more detailed description of engineering design:

> 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.

Variance among engineering standards can be demonstrated by comparing states' engineering design process standards. 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." Other states, such as Idaho and Indiana, for instance, have engineering design process standards that progress in complexity through the grade level bands.

Indiana's bands are kindergarten to second grade, third to fifth grade, sixth to eighth grade, and high school.

For those worried about overfilled curriculum silos, some of the states that have added engineering have reduced the size and number of standards by focusing on integration and overarching concepts. For example, Indiana's new science standards format poses all standards as process standards. Within the process standards, the nature of science and the design process of engineering are both explained and integrated into the four content areas of physical science, earth and space science, life science, and a new area called science, engineering, and technology. The science, engineering, and technology area utilizes science discovery to inform engineering design and problem solving as students design and improve technologies.

CONCLUSIONS

This study shows that engineering does exist in state standards across the nation. Students are learning about engineering (and technology) design formally and informally in both academic and vocational classrooms. The presence of 41 states with engineering in their standards contradicts the NAE reports of "no content standards" (Committee on Standards, 2010, p. 43) or "a few states" (p. 40) with standards. This large presence shows that pre-college engineering, just like educational standards, is not going away soon (Rutherford, 2009).

The engineering community can promote the big ideas of engineering to improve college readiness for all fields and improve math and science performance across the board to help prepare "the most highly qualified, best prepared" college students (Committee on the Engineer of 2020, 2005). The big ideas have been found in existing standards, as listed in the discussion section. Further, the ideas expressed in the operational definitions tie together pre-college standards and the needs of college engineering and are present throughout the documents analyzed in this study. Engineering as an iterative process that utilizes math tools and scientific knowledge to solve problems is reflected in various degrees throughout existing standards documents.

This review of standards from across the nation provides further opportunities to compare what others are doing with the effort in Massachusetts, Ohio, Texas, Minnesota, New Jersey and many other states. Mississippi's example of engineering standards integrated into mathematics is but one instance of how the standards database can be utilized by other standards stakeholders.

Moving Forward with Engineering Standards

The engineering community needs to build on the momentum made possible by the increased interest in and funding for STEM education and build on what is already being done in pre-college engineering. Standards have been evolving over the past few decades and engineering has found its way into classrooms across the nation. The National Governor's Association and the Council of Chief State School Officers have driven the move towards national core standards in order to eliminate the variability of what is being taught in our schools (National Governor's Association, 2010). The engineering community still has time to take a role in the development of the core science standards so that they include well-integrated big ideas from engineering (National Governor's Association, 2010; Committee on Conceptual Framework, 2010; National Assessment Governing Board, 2010).

While the NAE Standards Committee has called for more research on the cognitive aspects of engineering education, mounting evidence already shows the positive impact of applying math and science concepts in engineering contexts. Engineering has a place in the core standards movement (Committee on Conceptual Framework, 2010) and the engineering community can ensure that not only that foundational skills and math and science applications are included but also that the creative aspects of engineering (Center for Science, Mathematics, and Engineering Education, 1995), "the inspirational, optimistic aspects" (Tate et al., 2010, p.381) can be emphasized

Students see engineers as performing manual labor and tasks that require only lower-level thinking (Fralick, Kearn, Thompson, & Lyons, 2008) rather than seeing engineering as creative, rewarding and lucrative. Even teachers have misconceptions about engineers and think of them as builders and construction workers (Duncan, Oware, Cox, & Diefes-Dux, 2007). "Students want their careers to be lucrative, rewarding, limitless, creative, multi-disciplinary, and include travel and group work" (Taylor Research Group, 2000). However, they do not realize that 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) (CNN Money, 2010). The engineering community can help erase these misconceptions and show students how to use engineering in their own lives and to better society (Chae, Purzer, & Cardella, 2010).

In 1993, the nation needed "world-class academic standards" to help students "compete successfully with students of any country in the world (National Education Goals Panel, 1993, p. 1)". The engineering community has seen other educational fields go through design and iteration cycles to create state and national standards. Since the National Academy of Engineering and National Research Council called for the United States to resume its position atop the engineering world in 2009 (National Academy of Engineering, 2009), engineering education has a renewed impetus just as the national core standards movement approaches.

There are barriers to overcome in implementation of standards. In this respect, many refer to Massachusetts as the standard-bearer for pre-college engineering standards (Foster, 2010; J. B. Hansen, personal communication, 2010; Pearson et al., 2010), Massachusetts has shown that engineering standards can drive curriculum development, assessment design, and teacher preparation and that engineering can fit into academic curriculum while supporting science, mathematics, and technology programs (Foster, 2010). Similarly, Massachusetts stands as an example that engineering standards design is an iterative process that can be guided by examining what others are doing.

While explaining the urgent need to develop a consensus on engineering standards, this study has shown the extent of engineering content already present in U.S. standards: there are engineering and technology design-related standards in 41 states. Thirty-six states have strong explicit engineering standards and six states have strong standards where engineering is presented in the context of technology design. Of these, 17 were developed independently from ITEEA and PLTW standards or curriculum. Engineering is most often found in science standards (12), but also in areas variously labeled as technology, engineering and technology, STEM, and career and vocational standards, even in one case in math standards. The majority of standards found relate to design process knowledge or applications, specific parts of the design process and assessing technology impact and innovations. While engineering-related standards are inconsistent in scope, emphasis, location, subject area, and context, the coherence of core big ideas that emerge from the various standards indicates that a consensus on pre-college engineering curriculum is possible. Truly, engineering state standards provide rich information and concrete examples of ways that engineering is already integrated into curricula across the nation.

Given the strong momentum of increased interest in STEM education in the United States, along with the already strong presence of engineering standards in curricula at the state level, now is the time to move forward in the formation of a national pre-college engineering education agenda and a standards debate.

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