Summary

Every student requires STEM (science, technology, engineering and mathematics) literacy for academic success, potential career opportunities and as a contributing member of society. The benefits and promise of possibilities are diverse and numerous. Student interest and identity in the STEM disciplines may be transformative when educators are empowered with best practices. Increased conceptual learning within the disciplines is achieved when integrated STEM education concepts and practices are a component of students’ engagement with STEM disciplines. Yet integrated STEM education is still taking shape. While the “curriculum core disciplines” of science education and mathematics education both have robust, established knowledge and practice bases, the technology education discipline has a more circuitous history, and conversely K-12 engineering education has been non-existent until recently. This paper explains why engineering education is necessary for quality integrated STEM education. To this end, the University of St Thomas has developed a robust science, mathematics, technology, elementary, early-childhood, informal education complement for in-service and pre-service educators: engineering education for the educator. The UST engineering education graduate certificate and undergraduate engineering education minor codifies educators’ skills and knowledge in engineering education and integrated STEM education. The knowledgeable and skilled educator with engineering education competence, in turn empowers all PK-12 students in both formal and informal learning environments.

Background

A compelling argument has been made in the literature for a quality STEM workforce based on national defense threats and economic need due to globalization. The demand for STEM occupations are projected to grow faster than average, and pay, on average, is twice the median annual wage (DOL). The urgency for STEM education, was generated by a string of reports and literature cited at the beginning of the millennium. Titles self-describe the arguments: NAE/NRC 2002 Technically Speaking: Why All Americans Need to Know More About Technology; The National Academies 2007 report, Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future; and Friedman’s 2005 The World is Flat: A Brief History of the Twenty-First Century.

Parallel to the discussion on STEM education needs, due to economic and security concerns, was an educational reform which launched national academic standards in the core disciplines of mathematics, science and English. These national standards had a residual effect of producing a coherent framework for studying how students learn. The early national level science standards, rising out of the 1990’s “Science for All Americans” project, incorporated engineering and resulted in a rich body of knowledge on how students learn science. This understanding of learning in combination with advances in science led to the 2013 Next Generation Science Standards (NGSS). The precursor NGSS document, A Framework for K-12 Science Education: Practices, Crosscutting Concepts and Core Ideas, outlines research evidence for students to participate in their acquisition of science. In addition to a deeper knowledge base, students’ participation in learning allows for a broader more diverse student body to engage in STEM, to achieve success and to potentially transform their identities with respect to the STEM subjects (Honey). Interspersed within the national discussion was the role that engineering should play in education. The NAE/NRC 2009 Engineering in K-12 Education: Understanding The Status and
Successful K-12 STEM Education pointed to benefits of incorporating engineering into the classroom and the need for integrating STEM education and not further isolating disciplines. The Next Generation Science Standards (NGSS) shifts academic science standards beyond the traditional disciplinary core content of physical science, life science, and earth and space sciences to also include engineering, technology and application of science as a disciplinary core content area. In fact core content is only one of the three dimensions of the NGSS performance expectations. A second NGSS dimension is crosscutting concepts which “unify the study of science and engineering through their common application across fields and core ideas in the major disciplines of natural science” (NRC 2012). Crosscutting concepts include patterns; cause and effect; scale, proportion and quantity; systems and system models; energy and matter; structure and function; and stability and change. The third dimension, science and engineering practices, explicitly connects the process of science and engineering to the core content and crosscutting concepts. The eight NGSS practices of science and engineering are 1. asking questions (for science) and defining problems (for engineering); 2. developing and using models; 3. planning and carrying out investigations; 4. analyzing and interpreting data; 5. using mathematics and computational thinking; 6. constructing explanations for science) and designing solutions (for engineering); 7. engaging in argument from evidence; and 8. obtaining, evaluating and communicating evidence.

Integrated STEM education requires students to connect concepts, practices and mind-sets across science, technology, engineering and mathematics, as well as all other content areas. These stand-alone discipline silos have evolved independently but now must explicitly interlink theory and application for students to experience powerful learning. Science education and mathematics education both have a strong history, theoretical foundation and research base from which to draw epistemologies, content and methods, albeit a very separate and distinct history and knowledge base. Technology education has a more circuitous history which began tangential to collegiate engineering education but quickly deviated. And relative to the S, T, and M branches of knowledge, K-12 engineering education, until recently, was non-existent.

During this same time period, university level engineering programs exploded. The Morrill Acts of 1862 and 1890 endowed land-grant colleges which were commissioned to teach practical arts including
Engineering and agriculture. Engineering schools grew from five in 1860 to eighty-five in 1880 (Wirth). MIT President, John Runkle and Washington University’s Calvin Woodward “shared the ideal of creating a new breed of engineer who would be both technically competent and sensitive to civic needs. Both were discouraged by evidence that engineering students lacked rudimentary skills in the use of tools and knowledge of basic mechanical processes” (Wirth). Runkle, Woodward, Prosser, Snedden and others established “manual training” schools across the country. These programs, often established in connection to engineering schools promptly found their bases in schools of education or as stand-alone programs. While engineering was peripheral to the original curricula, once out of the influence of engineering programs, technology programs determined their own destiny. As external pressures changed, so did the curriculum, and successive name changes: manual training, manual arts, industrial arts, industrial education, technology education, and now technology and engineering education. Declines in enrollment and collegiate offerings of technology teacher education accompanied the circuitous path (Volk). In Minnesota, St. Cloud State University has the only technology education program with four to eight graduates per year (Lindstrom).

A nuanced demand is increasing for engineering education both as a stand-alone subject and as an element of integrated STEM education. Proprietary curricula has quickly filled the void. The National Center for Technical Literacy, Museum of Science, Boston has constructed K-12 engineering education programs but is best known for the “Engineering is Elementary” series. Project Lead the Way (PLTW) has also constructed K-12 curricula, the original high school curricula being most often cited. Critical to the success of these programs is the combination of teacher training, materials and equipment. Yet mathematics and science is not proprietary information. And costs associated with these programs often means that financially challenged schools, and thus students, do not have access to either stand-alone engineering or integrated STEM curricula. But why should students be limited to only proprietary engineering? Educators need a full robust engineering-education knowledge base to authentically teach engineering education. The need is now critical since engineering is incorporated into science standards!

Colleges of Engineering have traditionally focused on the future practicing engineer. Barriers to non-engineering students participating in engineering coursework are numerous. Shortcomings in mathematical achievement has traditionally been the first barrier for non-engineering students. Challenging, competitive engineering college cultures has posed a barrier for students in engineering programs (Seymour). Teachers’ self-beliefs and self-efficacy issues have also been cited as a barriers to participation in engineering coursework (Grasso, NAE 2010). This lack of access to engineering coupled with mathematics challenges has a spiraling effect where teachers are limiting mathematical and engineering achievement in their own classroom (Beilock). Teachers perceptions of engineers and engineering, which are transmitted to students, do not align with both the reality and need (Yassar). Successful engineering education experiences are needed for educators, if integrated STEM and engineering education is to flourish.

 Solution

The need for engineering education is clear.

“The expertise of educators in classrooms and in after-/out-of-school settings is a key factor - some would say the key factor - in determining whether integrated STEM education can be done in ways that produce positive outcomes for students. One limiting factor to teacher effectiveness and self-efficacy is teachers’ content knowledge in the subjects being taught ... The small amount of available data for K-12 technology teachers, many of whom are providing
The emergence of K-12 engineering education provides innovation in delivery and content. Engineering is the “glue” that makes math and science meaningful and relevant to students. Engineering provides a context in which problem solving is experienced and refined. Engineering is the framework for engineering practices as outlined in NGSS: defining problems, developing models, analyzing data, interpreting data, using mathematical and computational thinking, designing solutions, engaging in argument, and obtaining, evaluating, and communicating information. Successful K-12 engineering experiences expands career cluster pathways to a wider diversified population. And engineering experiences provides our future citizens and leaders with a greater range of problem solving tools as it educates them on the built environment and built systems which define their lives.

K-12 integrated STEM education is emerging and the need for an expansion of the engineering component as it relates to integrated STEM is necessary. Progress in teacher education systems takes time. Challenges to a more timely evolution include the historical establishment of K-12 teacher preparation content; content and enrollment challenges in technology teacher preparation programs; slowly evolving teacher preparation programs; teacher fear of engineering education; and barriers to collegiate engineering education. But innovative strides are being made by engineering colleges working in combination with education colleges. Organizations dedicated to improving K-12 engineering education include American Society for Engineering Education (ASEE) K-12 Division and the National Academy of Engineering (NAE) Center for the Advancement of Scholarship on Engineering Education (CASEE). Higher education institutions are working within these organizations to establish a collective coherent research agenda for engineering education. The Engineering Education Community Resource list has listed 12 engineering education and related undergraduate bachelor’s degrees, 2 undergraduate engineering education minors; 6 engineering education related minors; 26 graduate engineering education/STEM education graduate programs; 10 engineering education related graduate certificate programs; and 10 cross discipline programs.

In addition to research on learning, innovation sparked by engineering education has been one of the drivers of education change. MIT established FabLabs, and now Maker Spaces dominate progressive formal and informal learning environments. These spaces eliminate barriers within disciplines. STEM has expanded to STEAM, with an A for arts, and SHTEAM, with an H for humanities. Epistemological stances and pedagogues supporting these approaches draw from a wide and established set of educational philosophers, including Maria Montessori, Friedrich Froebel, Lev Vygotsky, Jean Piaget, Seymour Papert and John Dewey, and are cited in the research emerging from these constructions.

The University of St. Thomas is the only higher education institution in the mid-central states to offer both an engineering education minor and an engineering education graduate certificate. Also noteworthy is that the UST Center for Engineering Education is housed within the School of Engineering and jointly supported by faculty from both the School of Engineering and the College of Education, Leadership and Counseling. This positions UST to take the lead in innovative integrated STEM educational offerings. The Center for Engineering Education draws upon the undergraduate engineering programs which holds the distinction of being a leader in liberal arts engineering. Liberal arts engineering dispels the false dichotomy of liberal education or technical education and harkens back to the early need to meet “the ideal of creating a new breed of engineer who would be both technically
competent and sensitive to civic needs.” That is the need for competent thinkers who engage into today’s 4C’s: critical thinking and problem solving; communication; collaboration; and creativity and innovation (NEA). But most importantly, the Center for Engineering education provides low-cost innovative engineering education as a critical complement for ALL EDUCATORS and therefore ALL STUDENTS. Curriculum provides a meaningful context for the science, technology and mathematics that students engage in daily.

Conclusion

The capacity to accelerate every learner’s capabilities, interest and identity in STEM education is within reach. Forward thinking university level engineering programs are engaging educators in rigorous, meaningful engineering education both as a stand alone subject and as the element that binds the science, technology and mathematics in integrated STEM. The University of St. Thomas engineering education program seeks to provide all science, technology, mathematics, elementary, early childhood, library and, frankly every other teacher, with the tools needed to authentically provide the engineering education component of STEM education.


Dr. Deborah Besser, is a licensed engineer with a breadth of teaching and engineering experience. Currently, she is the director of University of St. Thomas Center for Engineering Education where she teaches engineering education. Previous professional experience includes instruction in structural systems (steel, timber, concrete, masonry), statics, strength of materials, engineering economy, construction materials, construction management and graphic design. Dr. Besser, who holds a PhD in education, entered the K-12 education realm as program director where her responsibilities included design and implementation of K-12 engineering education programs, including Project Lead the Way educator training. Prior to teaching, Dr. Besser was a design engineer with HNTB-CA, where she worked on seismic retrofits and new design of high profile transportation structures. The unifying theme of her vocational mission is that she is committed to building bridges.

Dr. AnnMarie Polsenberg Thomas is the founder of the Center for Engineering Education as well as the founder of the Playful Learning Lab. MIT and CalTech trained, AnnMarie is an associate professor in the School of Engineering, the Schulze School of Entrepreneurship, and the Opus College of Business at the University of St. Thomas. She is also the Founding Executive Director of the Make Education Initiative, where she established the national Maker Corps program.