The Impact of Engineering Education at the Kindergarten to High School Levels

A Review of Research

By

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Abstract

The aim of this review is to describe a selection of international research efforts in Kindergarten through Grade 12 (K-12) engineering education in order to define an organizing framework for the impact of engineering education on students' development of technological literacy, learning of math and science content, and motivation and understanding of science, technology, engineering, and math (STEM) careers. A considerable and renewed interest in the field of K-12 engineering education in the United States (US) motivates the need for sharing theoretically grounded research (Benenson, 2001; De Miranda, 2004; Householter, 2000; Norman & Roberts, 2001; Pellegrino, 1999; Zuga, 2000).

The organizing framework that is presented in this paper includes research strands in five broad areas: attitudinal, social, cognitive, cross-curricular or interdisciplinary learning, and early career awareness. Research exploring the impact of engineering education on students' attitudes suggests that such learning experiences promote increased feelings of motivation and self-efficacy (Atkinson, 1999; Murphy & Hennessy, 2001; Rowell, 2002). Research exploring the social impact of engineering education suggests that it promotes student learning and collaboration (Atkinson, 1999; O'Connor, 2000). Research exploring the cognitive impact of engineering education suggests that such learning experiences can build creative design skills and foster the utilization of higher order thinking and problem solving skills (Amsel, Goodman, Savoi, & Clark, 1996; Fleer, 1999; Foster & Wright, 2001; Roden, 1995). Research indicates that engineering education can serve as a vehicle to effectively integrate and teach in an interdisciplinary fashion content areas such as math and science (Barlex & Pitt, 2000; Cross, 1998; Rogers & Portsmore, 2004) and finally, engineering education can promote technological literacy and early career awareness in engineering and other applied math and science fields (Hill, 1990; Solomonidou & Tassios, 2007).

This review highlights selected research in the fields of engineering education, technology education as well as design and technology education. In this paper, I will collectively refer to these as engineering education. At the same time, this effort reveals some gaps in the amount and quality of research studies in the field, particularly in the cognitive research strand.

Engineering education may hold important benefits for children of all ages and must continue to be researched.

The Impact of Engineering Education at the Kindergarten to Pre-College Levels

A Review of Research

Introduction

The primary purpose of this literature review is to bring to light the findings of educational research efforts that examine the impact of involving elementary through high school aged children in engineering educational experiences. While industrial arts and vocational technology education programs have existed in the United States' (US) public education system in various forms since the early 1900s (Swortzel, 1997), engineering education has normally been reserved as a field of study for the college and university levels. However, in the last decade, preeminent engineering and technology professional groups in the US, such as the American Society for Engineering Education (ASEE), the National Academy of Engineering (NAE), the National Science Foundation (NSF) through its National Center for Engineering and Technology Education (NCETE), and the International Technology Education Association (ITEA) have made formal and significant outreach efforts that focus on children's engineering education as a vehicle for developing technological literacy for all US citizens through outreach, curriculum, and improved instruction beginning with students at the very youngest levels—kindergarten through twelfth grade (K-12). This considerable interest in the field of K-12 engineering education is also evident in the activities of many universities as well as public and private sector groups that have embarked on the development of engineering curriculum for young children such as City Technology (Benenson, 2001), Children Designing and Engineering (Hutchinson, 2002), Engineering is Elementary (Museum of Science, 2007), and Engineering by

Design (ITEA, 2007). Another program that has experienced tremendous growth in the last ten years is 'Project Lead the Way,' a pre-engineering professional development and student pre-engineering curriculum that has grown from a regional presence in ten schools in the state of New York in 1997 (National Society of Professional Engineers, 2003) to over 1,500 schools in forty-five states by 2007 (Project Lead The Way, 2007). Many of these efforts have purposefully focused on the K-12 grade levels. The ASEE, for instance, formed a K-12 Engineering Education Center in 2004 to "identify and gather in one place the most effective engineering education resources available to the K-12 community" (American Society for Engineering Education, 2007, p. 1). In 2005, the National Academies formed a special committee on K-12 engineering education with the goal of providing guidance for reform by reviewing literature, curricula, and instructional approaches in the field (National Academy of Sciences, National Academy of Engineering, Institute of Medicine, 2007). Yet, in spite of all of this interest, collaborative reports, and policy recommendations, there is still sparse research-based evidence regarding the specific impact and benefits of engineering education. There are also varying levels of agreement regarding the fundamental elements of a K-12 engineering curriculum, and there is minimal research on best practices for teaching and assessing engineering learning. Many engineering curriculum development and pre-engineering programs are being implemented based on intuitive rationale but few are based on consistent theoretical foundations and empirical research findings, although many new efforts are now underway (Benenson & Piggott, 2002; Cunningham & LaChapelle, 2007).

The goal of this review is to organize and synthesize families of existing research efforts that have examined the impact on students in the K-12 levels who participate in engineering learning experiences. This broad review will examine the definitions of related engineering education terminology and purposely seek to focus on the breadth of research initiatives on the topic rather than to explore any one area in depth. This will support the overall goal of providing a view of the variety of international research efforts in Kindergarten through Grade 12 (K-12) engineering education. This will also help to define the organizing framework for the impact of engineering education on students' development of technological literacy, learning of math and science content, and motivation and understanding of science, technology, engineering, and math (STEM) careers. Once summarized, an analysis will highlight common findings and gaps that together begin to define a research agenda for the further study of specific benefits to students.

What is Engineering Education at the K-12 level?

There is a problem of terminology that must be immediately addressed in order to proceed with clarity. In the literature, there exist at least six different broad categorical terms to describe similar objectives and approaches that are in some way related to engineering education (see Figure 1). These six terms are:

1) Design education (Archer, 1979; Cross, 1982; Steers, 1990)
2) Technology education (Association for Educational Communications and Technology [AECT], 1977; ITEA, 2000)
3) Design and Technology education (Archer, Baynes, & Roberts, 1992)
4) Engineering Technology (Engineering Technology Leadership Institute [ETLI], 2007; Massachusetts Board of Education, 2005)
5) Engineering Design (Accreditation Board for Engineering and Technology [ABET], 1998; Dym & Little, 2003)
6) Engineering Education (Burrus,2006; Petroski, 2003)

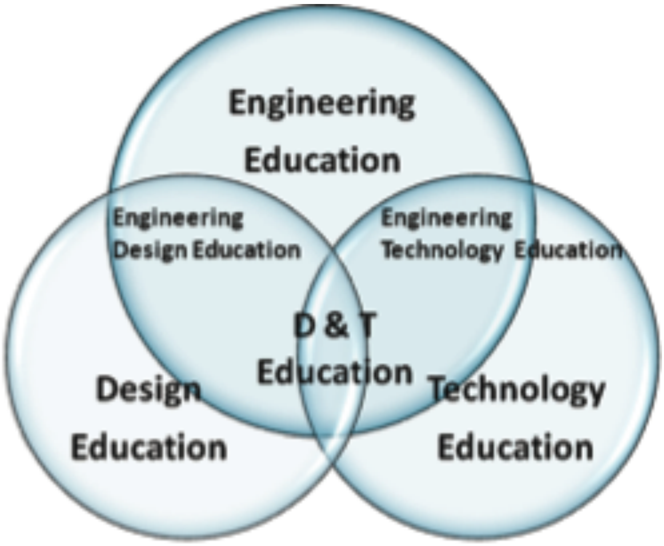


Figure 1: Engineering, Design and Technology Education

The position that will be adopted in this paper is that at the K-12 level, there is some degree of overlap among these different terms, as highlighted in Figure 1. Engineering education includes aspects of engineering design education, engineering technology education, design education, technology education, and design & technology (D&T) education. Therefore, the unifying term of "engineering education," will be utilized throughout this paper.

Design Education

Design, like art, is about aesthetics and visual reactions (Rotte, 1993). However, art can be differentiated from design in that art may seek only to express a point of view through a personal aesthetic, but design, while dealing with form, also seeks to provide a purpose, or function, related to solving a problem or answering a need. The commonly used phase of "form follows function" derives from an essay by the noted early nineteenth century architect, Louis H. Sullivan, who in contemplating the design of tall office buildings, philosophically considered design in nature, and concluded the idea of form following function in the following way:

> It is the pervading law of all things organic and inorganic, of all things physical and metaphysical, of all things human and all things superhuman, of all true manifestations of

> the head, of the heart, of the soul, that the life is recognizable in its expression, that form ever follows function. This is the law. (Sullivan, 1896, p. 8)

While there are varying opinions as to how form and function interact (Michl, 2002), there is agreement that design is concerned with this idea of function, interaction, or purpose and in this way goes beyond the visual and even physical (as with designed processes) and is a point of connection between art, science, and technology (Design Council, 2005; Pye, 1964). Some in design education have argued for design as a third area of learning, separate from science or the humanities: "Design, in its most general education sense…is defined as the area of human experience, skill and understanding that reflects man's concern with the appreciation and adaptation of his surroundings in the light of his material and spiritual needs" (Archer, 1979, p. 16). From this perspective, design affords not only pleasing and useful end products, but is a process in itself and a powerful form of communication that can be described by the following characteristics, as proposed by Archer (1992):

Useful- inclusive of an operation value;

Productive- an active science considering a real object or system;

Intentional- as it is premeditated and considered in light of complex technical and social issues;

Integrative- as it employs systems thinking and adaptation to a prescribed environment;

Inventive- as it involves a new idea or application of a creative set of ideas;

Expedient- as the design activity is then judged by its results and not necessarily by the means alone.

The roots of design education also extend to design research that holds as a goal to understand knowledge as it embodies the "configuration, composition, structure, purpose, value, and meaning in man-made things and systems" (Archer, 1979, p. 2). Design in this context centers around technology and any other environmental components of the human for whom one is designing. In this way, design embodies both art and engineering. The study of design as an academic subject is credited to Bruce Archer, an English mechanical engineer who went on to lead the Royal Academy of Arts. Archer's six basic stages of a systematic design method include such milestones as programming, data collection, analysis, synthesis, development, and communication. This view of design education was to form the foundation for what would later become design and technology education in the United Kingdom (UK).

Design education in the sense that has been discussed above centers on the idea of intent and function. This is related to a central definition of engineering education and engineering design education (Norman, J. 2001). Engineering education presents to students the field of engineering by instructing in the engineering conceptual topics such as mechanics, thermodynamics, and aerodynamics, with an emphasis on both theoretical and practical aspects. Engineering design methodology is a critical element of engineering education and, like design, is driven by a process and systems view that necessitates a clear understanding of problem and needs as well as a comprehension of technical requirements and environmental and social constraints. As illustrated in Figure 1, engineering education includes design education as a critical subcomponent.

Technology Education

In the US, a curriculum called "Industrial Arts" was overseen by the industrial arts or technology education professional organization later known as the ITEA. Technology is defined as

> 1. Human innovation in action that involves the generation of knowledge and processes to develop systems that solve problems and extend human capabilities. 2. The innovation, change, or modification of the natural environment to satisfy perceived human needs and wants. (ITEA, 2000, p. 18)

According to ITEA (2008), technology education is a "problem-based learning curriculum that utilizes math, science and technology principals for the design, development and application of knowledge and processes to serve a specific need" (ITEA, 2000, p. 22). Technology education is a term broadly used to describe how humans modify the world around them to meet their needs and wants, or to solve practical problems. The Association for Educational Communications and Technology (AECT) defines technology education as a field that fundamentally applies a process towards the solution of problems (AECT, 1977). It was the ITEA that in 1985 spearheaded the effort to establish standards that promoted technological literacy for all students and their publication entitled "Standards for Technology Education Programs" (ITEA, 1985) would progress into the "Technology for All Americans Project" (ITEA, 1996) and finally into the widely recognized Standards for Technological Literacy (ITEA, 2000). The standards include subtopics related to the nature of technology; technology and society; design; abilities for a technological world; and the designed world. These standards identify recommended content or study that leads to attaining a minimal level of technological literacy. Technological literacy is defined by ITEA by describing the abilities of a technologically literate person: " A person that understands, with increasing sophistication, what technology is, how it is created, how it shapes society, and in turn is shaped by society is technologically literate" (ITEA, 2000, p. 4), Technology education, as presented above, deals not only with the "what" of technology, but the "how." In technology education, the term "technology" includes all engineered efforts, from the seemingly simple paperclip (Petroski, 1994) to the most complex software algorithm. In technology education, students learn how humans modify the world around them to meet their needs and wants and they learn a process for designing a range of technologies that solve problems of a practical nature. As illustrated in Figure 1, engineering education includes technology education in its realm since a broad range of technologies are included in engineering education, and like in technology education, the goal of engineering education is to design for a practical or functional purpose.

Design and Technology Education

Design and Technology (D&T) was adopted as a formal program of study in the UK national curriculum in 1990 for children in the equivalent US K-10 grades. D&T is a curriculum that integrates both design and technology. Technology is defined by Bruce Archer as "humankind's collected knowledge about tools of every sort; about how they work; and about where and how to use them" (Archer, Baynes, & Roberts, 1992, p. 7) and design is defined as a process "directed towards meeting a particular need, producing a practicable result and embodying a set of technological, economic, marketing, aesthetic, ecological, cultural and ethical values determined by its functional, commercial, and social context" (Archer, Baynes, & Roberts, 1992, p. 8). Together, these definitions for design and technology and their supporting philosophies explain how design and technology education has been practiced in the UK. During the more than twenty five years since D&T has formed part of the national curriculum, there have been many efforts to research the effects of this curriculum, especially among practitioners or action researchers. This has influenced other countries such as South Africa, Australia, and Canada to also institute D&T curricula in the K-12 setting. It has also led to the development of a field of research in education that focuses on D&T. The disconnect between the D&T organizations and experiences of other D&T education and engineering enducation country leaders such as Australia, Finland, Korea, Israel, The Netherlands, Turkey, the UK, and South Africa (among others), and the engineering education and technology education organizations in the US are bridged by an international effort called Pupils' Attitutes Toward Technology (PATT). PATT is an international organization based in The Netherlands that promotes research in engineering and technology throughout the world (PATT, 2008). Through this organization of international collaborators, there has been a very helpful sharing of philosophies and research findings since 1988. The topics presented in this collection of conference proceedings demonstrate the overlap between K-12 engineering education goals in the US and D&T education goals (deVries, 1999, 2005). Figure 1 shows D&T contained within engineering education. Both engineering education and D&T education include elements of design education and technology education, as discussed in previous sections, and seek to assess the impact of these efforts on student learning, motivation, and interest in career pursuits that depend on the technical, creative, and innovative problem solving skills fostered by D&T education as well as engineerirng education. D&T education, however, does not focus on a specific career discipline or application, such as engineering.

Engineering Design Education

Engineering design is sometimes viewed as a specific curricular approach, especially in methodologies that utilize "design challenges" and "engineering briefs." It is also often explored independently in research, but it is, in fact, a key component of engineering education in general. The Accreditation Board for Engineering and Technology (ABET) is a federation of professional engineering and technical societies whose main function is to accredit the wide variety of engineering, engineering technology, and computing and applied science programs at US colleges and universities. They define engineering design in a very complete way that includes many of the features mentioned in some of the previous definitions:

> Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic science and mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing, and evaluation. The engineering design component of a curriculum must include most of the following features: development of student creativity, use of open-ended problems, development and use of modern design theory and methodology, formulation of design problem statements and specification, consideration of alternative solutions, feasibility considerations, production processes, concurrent engineering design, and detailed system description. Further it is essential to include a variety of realistic constraints, such as economic factors, safety, reliability, aesthetics, ethics and social impact. (ABET, 1998, p. 10)

Figure 1 shows engineering design included as a very important part of engineering education. Some would argue that engineering design is the most critical component of an engineering education: “Thus, the most important recommendation is that engineers in academe, both faculty members and administrators, make enhanced design pedagogy their highest priority in future resource allocation decision” (Agogino, Dym, Eris, & Frey, 2005, p. 114). Likewise, in engineering education at the K12 level, the engineering sciences as content are beyond the learning objectives of young students, and therefore, engineering design is arguably the distinct element that is most important to engineering education.

Engineering Technology Education

The Engineering Technology Institute (ETLI) defines engineering technology education as an engineering education field that focuses on the "applied aspects of science and engineering" (ETLI, 2007, p. 1). This focus on the application rather than the theoretical aspect distinguishes engineering technology from engineering and is most relevant at the college level. Many specialized areas of engineering technology preparation (such as manufacturing, construction, communications, etc.) are accomplished through a community college program of study awarding an associates degree, versus the theoretical degree of 'engineering' awarded by a 4-year university. However, at the K-8 level, this difference is not as relevant. In 2001, Massachusetts became one of the first states to incorporate engineering and technology education as part of the state's public education learning standards for every grade, K-12 (Massachusetts Department of Education, 2001). Massachusetts developed a strand of standards called the Science and Engineering/Technology standards. By grouping these standards together, they underscore the close-knit relationship of science, engineering, and technology (see Figure 2).

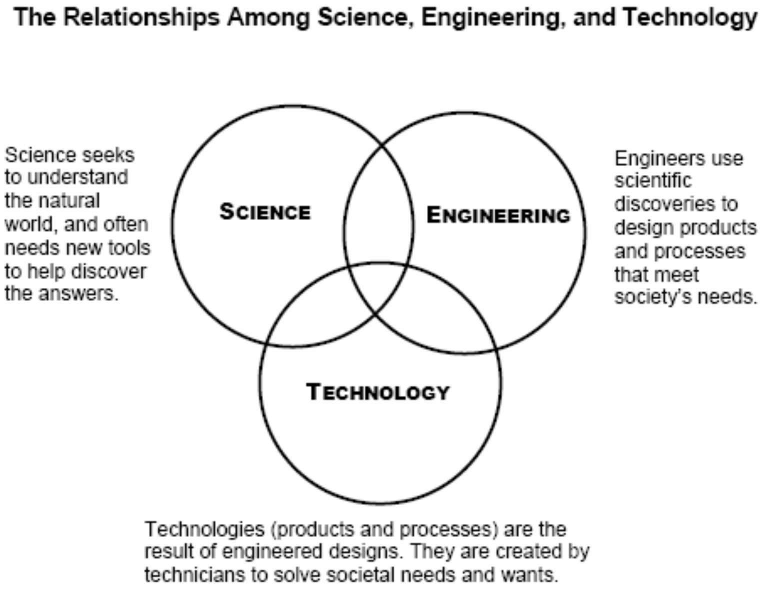


Figure 2. Relationship among science, engineering and technology

(Massachusetts Board of Education, 2005)

The standards sweep broadly from the earliest grades through high school and the science standards are outlined separately from the engineering/technology standards. The motivation for engineering/technology education at the K-12 level stemmed from the national mission of building technological literacy; but in many states, such as in Massachusetts, what is called for is both a focus on engineering content as well as a focus on an engineering design process. The engineering/technology standards include "Materials and Tools" and "Engineering Design" standards in the K-8 grade levels and expand to include engineering concept areas for the high school grades (9-12) including Materials, Tools, and Machines; Engineering Design; Communication Technologies; Manufacturing Technologies; Construction Technologies; Transportation Technologies; and Bioengineering Technologies (Massachusetts Board of Education, 2005). Students are encouraged to manipulate both natural and man-made materials and explore their uses around them. They are introduced to the engineering design process and they learn to recognize needs and problems, different ways of representing them, and they identify materials in their designs based on specific properties. The fact that Massachusetts chose to call this body of standards and curriculum “engineering/technology” seems itself an attempt to bring together these often separate bodies of learning objectives, curricula, and sponsoring organizations. Engineering education goes beyond the engineering, technology, and science relationship depicted in Figure 2, above. It also includes a relationship with other content areas such as mathematics, economics, and social-cultural studies. Engineering education and the above definition for engineering/technology education do hold in common the inclusion of an applied content focus through the use of a thoughtful engineering design process.

Engineering Education

The study of engineering has traditionally been a college level field of study that incorporates high-level mathematics and science coursework as well as specialized technologies into many specific fields of application such as electronics, industrial manufacturing systems, civil, mechanical, chemical and biotechnological systems as well as many others. In this light, engineering is truly the science and art of inventing for a purpose guided by a synthesis of knowledge, and constrained by natural science laws while taking into account wider issues (Petroski, 1996). The practice of engineering draws upon basic common sense skills and problem solving reasoning about materials, structures, energy, and systems. But the aspect of design and development is what sets engineering apart the most from science. Engineering includes invention, design, and development or manufacturing. The concept of failure is an idea that unifies engineering. From the design stage, failure criteria are determined: analysis of force and strength, form and function, as well as failure modes. Engineers use mathematics and science but they do so conservatively since they know that theory can seldom account for all the variability and detail that exists in reality. Math and science are used to calculate and predict the performance of a design before it is produced, but besides calculations, engineers also utilize trial and error methods that build on small improvements and follow general tendencies. Engineering also includes consideration of economic, social, environmental, ergonomic, and ethical factors. Engineers consider human factors and real world product usage including consideration of costs and social benefits. Professional engineers need expertise in various natural sciences such as chemical, physical, biological, and geological sciences, along with the engineering sciences of fluid mechanics, thermodynamics, and hydrology, mathematics, and computer science. Real world engineering efforts are shaped by culture, and politics and in turn shape the culture, politics, and times in which it is embedded. Engineering is differentiated from science as science is the study of naturally occurring phenomena and engineering is the application of knowledge of these phenomena and of principles in math and science in designing and developing usable devices, structures, and processes. Burrus (2006) defines engineering as “the endeavor that creates, maintains, develops, and applies technology for societies' needs and desires” (p. 1). Similarly, the international engineering workshops in 2004 defined engineering as,

> the creative application of scientific principles to design or develop structures, machines, apparatus, or manufacturing processes, or works utilizing them singly or in combination; or to construct or operate the same with full cognizance of their design; or to forecast their behavior under specific operating conditions. (Japan Accreditation Board for Engineering Education, 2004, p. 12)

Since the late 1970s, when engineering colleges found that more outreach programs were necessary to draw high school students to pursue engineering studies, there have been various initiatives that have taken engineering education into the schools and in so doing, have emphasized other important aspects of engineering education and the eventual adoption of this engineering way of learning and thinking, taking engineering education into children's primary and secondary studies.

Children's engineering education is the educational field concerned with the content and processes for providing kindergarten through high school students with relevant real-world learning experiences that introduce and reinforce age-appropriate skills focused on innovative problem solving through the design of functional technological solutions and the integration of knowledge. Balanced by a core set of science, technology, engineering and math fundamentals, engineering education is also an educational strategy for developing higher order thinking skills by presenting students with thoughtful problem solving, critical thinking, creative thinking, and self-assessment opportunities of a very wide range of technologies- allowing even the very youngest of children to understand the concepts of technology, design, and engineering. The engineering design methodology is ensconced within engineering, and allows students a level of inquiry motivated by the search for a clear understanding of problems and needs and equally, a comprehension of technical requirements and environmental and social constraints. The engineering design process not only reinforces independent thinking and self-awareness, but also encourages and rewards communication, teamwork, global thinking, and ethical considerations. Children's engineering education, as shown in figure 1,encompasses elements of design education, technology education, engineering design education, D&T education, and engineering/technology education, guided by research-based student learning standards, assessment methods, and recommended pedagogical, curricular, and professional approaches.

In consideration of the background presented and the objectives of these various terms as applied in education for students in the K-12 setting, this review will proceed by referring to all of these efforts as "engineering education."

A Call for More Research on Engineering Education in the US

The various efforts of implementing engineering education initiatives in various states across the US and the energy involved in determining if and how this important curriculum might be a key to improving STEM education have given rise to calls for more research in the field of engineering education. While there is a substantial base of design and technology education research in the UK and Australia, it is still lacking and does not yet constitute a full body of applicable and consistent research. Various meta-studies of research in engineering education at the K-12 level conclude that insufficient attention is focused on researching teaching and learning in the specific field of engineering education and so there is a call for a coherent research agenda to further establish the field and identify a clear direction (Householter, 2007; Lewis, 1993; Petrina, 1998; Soloman & Hall, 1996; Zuga, 1994).

The rationale for conducting research in engineering education is to better understand student learning, engineering education teaching approaches, and the impact of both. The following overarching research questions motivate this call for more research:

1) How and what do students learn when they are involved in engineering education?
2) What are the various areas of impact and benefit that engineering education has on students?
3) What approaches are fundamental for effective engineering education and for assuring teacher preparation in the area of engineering education?

4) What is the potential of engineering education for students to strengthen skills in related areas such as mathematics and science?
5) What is the extent to which engineering education might help students develop competencies in technological literacy and interest in STEM careers?

1. How and what do students learn when they are involved in engineering education?

More research is needed to determine how and what students learn when they are involved in engineering education activities and what theoretical underpinnings are more relevant for understanding children's learning of engineering. There are indications that engineering education borrows from constructivist learning theories (Piaget, 1992), social constructivist theories (Vygotsky, 1978), constructionist approaches (Papert, 1980) and situated cognition theories (Lave and Wenger, 1990). Observationally, some in engineering education maintain that engineering education approaches draw upon the constructivist learning theories. Jean Piaget's constructivist learning theory proposes that children construct their own knowledge through active experience, such as physical and sensory experiences that lead to constructing and organizing patterns of ideas (logico-mathematical knowledge), and experiences guided by taught social practices (social-conventional knowledge) (Piaget, 1992). The designing and creating activities within engineering education certainly qualify as physical and sensory and may, in essence, demonstrate the internal understandings that are constructed in children's minds. Constructionism, an approach developed by Seymour Papert (1980) with the theoretical underpinnings of Piaget's framework, asserts that children create and are most engaged when they identify a personal meaningfulness to a particular activity. Constructionism focuses on the significance of children making things in the process of learning, on using tools and technology to design and create artifacts and on engaging in conversations that facilitate the construction of new knowledge. Engineering education learning experiences have this potential for engaging the student as students consider, design, and construct artifacts that are personally meaningful. Students are able to participate in this way since early childhood through their play, use of imagination, ability to create and design, and because of their easy acceptance of technologies such as robotics, computers, and even building blocks (Bers, 2007).

But engineering education is also defined by the collaborative and communication–rich interactions that take place between peers, teachers, and/or other experts. In this way, engineering education experiences include the cultural mediation and social learning experiences highlighted in the learning theory of Lev Vygotsky (1998), who maintained that such social learning interactions and cultural mediation contribute fundamentally to the development of a child's cognition and higher learning functions. Furthermore, the use of tools and technologies and the development of self-guided design helps students internalize and "appropriate" or make the learning their own (Vygotsky, 1978). Theories of situated learning point out that learning is not only socially influenced, but reliant on the particular social situation in which the learning reference is embedded (Lave & Wenger, 1990). Researchers in this area insist that engineering education instruction should be grounded in cognitive science and cognitively based instructional models such as collaborative learning, socially distributed expertise, and project based instruction (DeMiranda, 2004; De Miranda & Folkestad,2000).

2. What are the various areas of impact and benefit that engineering education has on students?

In 1999, an international conference on engineering education (PATT-9) chose to examine the impacts of engineering education as its theme. However, research was still weak in this overall arena, and the editor concluded that "In general we can say that our conference theme seems to have put us in an embarrassing position: although in several countries by now we have had at least a decade to prove the reality of the impact that we claimed Technology Education would make, we do not (yet) have an empirical basis for that" (DeVries, 1999. p. 116). At the same time, some initial empirical efforts were beginning in 1999 and in the 2007 conference, over fifty papers were presented from across the international member countries and many of these featured empirical research efforts (PATT 18, 2007). Certainly, much more research is required and a framework for analyzing this strand of research would be helpful. The following sections will focus on presenting such a framework and summarizing some key findings from a selection of research studies.

3. What approaches are fundamental for effective engineering education and for assuring teacher preparation in the area of engineering education?

As engineering education learning objectives and standards begin to be mandated for younger student populations as in Massachusetts and New York (S. Rogers, 2006), it is essential to utilize research-based knowledge to define the most effective instruction methodologies and approaches for training and developing teachers in both required grade-level content and pedagogical approaches. This area of research is also sparse and research coalitions that are focusing on this area in both research and educational programs and policies report that in general teachers have a positive outlook on engineering education and believe that it is important to teach engineering concepts in the classroom,. However, they seek additional training and they are concerned about the "inaccessibility" of engineering education and engineering careers for some segments of their student populations as compared to others (Douglas, Iverson, & Kalyandurg, 2004).

4. What is the potential of engineering education for students to strengthen skills in related areas such as mathematics and science?

Science, technology, engineering, and mathematics share a long historical relationship going back many hundreds of years to the time of ancient civilizations and their use of mathematics and technology to describe and address scientific phenomena and solve problems in astronomy, chemistry, medicine, physics, etc. (Dorn & McClellan, 1999). Mathematics is an analytical tool used to help understand relationships and patterns using scientifically derived data. Mathematics and science share many features in common with technology and engineering as described by the AAAS:

> a belief in understandable order; an interplay of imagination and rigorous logic; ideals of honesty and openness; the critical importance of peer criticism; the value placed on being the first to make a key discovery; being international in scope; and even, with the development of powerful electronic computers, being able to use technology to open up new fields of investigation. (AAAS, 1990, chapter 2 online)

This strong connection between science, technology, engineering, and mathematics is also evidenced by the commonly used acronym of “STEM” that links these four areas as key educational needs for all students in preparation for careers in the twenty first century (NSF, 2007). For this reason, in a discussion regarding engineering education progress, it is relevant to consider the status of mathematics and science education. For almost twenty years now, there has been national concern over lagging US student achievement results in science and mathematics as compared internationally. The Trends in International Mathematics and Science Study (TIMSS) is one of the largest international studies of student achievement in mathematics and science. It was launched in 1994-95 as a benchmark study conducted at five grade levels in more than 40 countries testing student achievement in mathematics and science for more than half a million students (Beaton, Gonzalez, Harmon, Kelly, Martin, Mullis, Orpwood & Smith, 1997.) The US students' performance as measured in 2003, was mediocre at best in most grade levels and this further pushed the awareness level and need for action to improve instruction and student achievement in science and math as well as engineering and math (Mulis, Martin, & Foy, 2005).

5. What is the extent to which engineering education might help students develop competencies in technological literacy and interest in STEM careers?

In 2003, the relatively low levels of technological literacy among US citizens, as measured by the ITEA's survey of Technology for All Americans coupled with the low science and mathematics results in the TIMSS (2003) led to sounding a louder alarm. Even at the general societal level, many people in the US were found to be lacking in general understanding of science and technology. Apparently, citizens had grown accustomed to being on the receiving end of user-friendly, technically transparent services such that they now lacked the technical literacy required to help them make informed choices and understand their changing world (National Academy of Engineering and the National Research Council: Committee on Technological Literacy , 2002).

One of the goals of engineering education is that through it, student technological literacy and interest in science, technology, engineering, and mathematics careers be developed. It is particularly important to assure that the full range of the population of students in the US participate in engineering education, in order to prepare interested students to fill future career opportunities. The US Bureau of Labor Statistics projects a continued and growing demand for jobs in the science and engineering sector (Science and Engineering Indicators, 2004). However, an aging, largely white male science and engineering workforce, a decreasing presence of foreign nationals in these professions, and a shift in the demographics of the US, point to a potentially critical shortage of engineers. The US' demographic patterns have continued to shift and change in large part due to growth in the population of traditionally underrepresented minority groups (African Americans, Native Americans, Hispanics, Pacific Islanders, and some Asian Americans). The minority population was over 100 million in 2007, or about 30 percent of US residents. Hispanics are the largest minority group, representing 15 percent of the total US population, at 46 million people. African Americans are the second-largest minority group, totaling 41 million people (US Census Bureau, 2007). However, the participation of traditionally underrepresented minority groups in engineering careers is very low. Only about 11 percent of the engineering workforce is African American, Latino, and American Indian (National Science Board, 2006). The National Science Board indicators project for minorities (including Asians/Pacific Islanders, Blacks, Hispanics, and American Indians/Alaskan Natives) to make up 52 percent of the college-age (18–24 years old) population of the US by 2050. So minority youth, as the major part of the US's growing population, are the untapped national resource that can fill the gap of science and engineering professionals in the United States.

A Framework for a Review of the Research

After reviewing the literature on engineering education, various categories of impact on learners are apparent. Zuga's (1999) review of the research has found impact in the following areas: social skills; student motivation; personal affect; skill development; and academic achievement. Wilson and Harris's (2004) review of the effect of the design and technology curriculum in the UK identifies an impact in the following four areas: attitudinal and affective;

social; cognition; and cross-curricular learning. Reviews of some of the most current efforts, including research from 2005-2007 in the US and Australia (Amsel, Clark, Goodman, & Savoi, 1996; Atkinson, 1999; Barlex & Pitt, 2000; Cross, 1998; Fleer 1999; Foster & Wright, 2001; Hill, 1990; O'Connor, 2000; Roden, 1995, Rogers & Portsmore, 2004; Rowell, 2002; Murphy & Hennessy, 2001) indicate five areas of impact: 1) early career awareness; 2) cross-curricular learning; 3) cognitive development and higher-order thinking; 4) social skills and cooperative learning; and 5) student attitude and motivation. The model in Figure 3 presents an organizing framework, and while some impact areas are more utilitarian (such as early career awareness), others are more substantial and explore not only curriculum strategies but also the deeper, more meaningful impact upon cognition, social skills, and affect on students involved in engineering education.

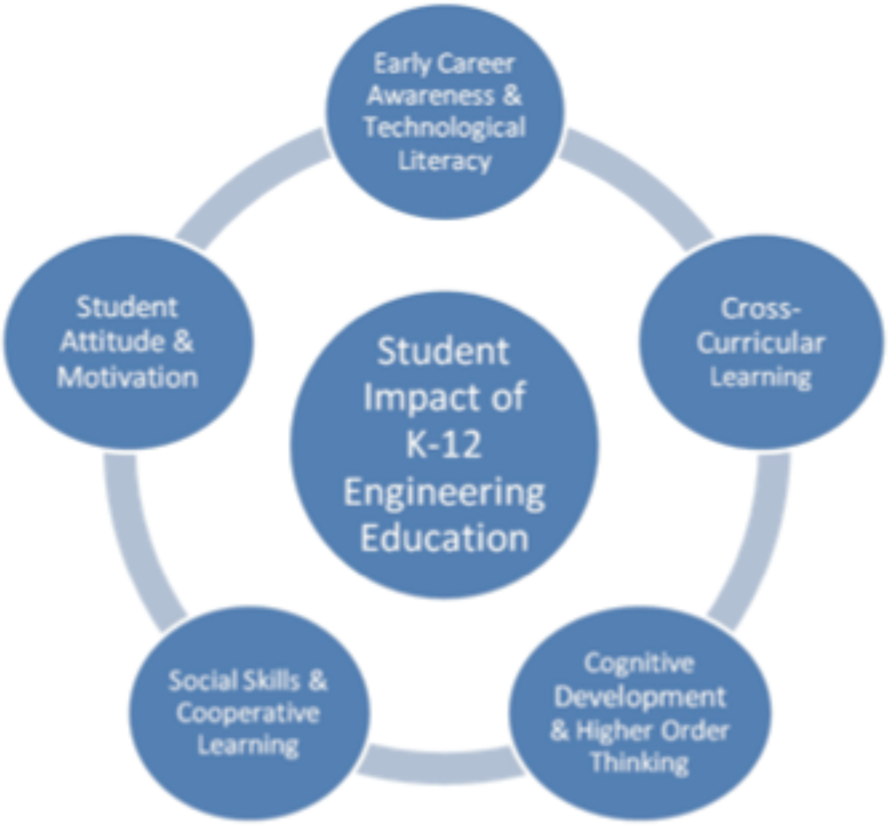


Figure 3. Impact of K-12 Engineering Education Framework

Table 1 outlines the studies that were reviewed as a representative sample of research in the five areas of impact presented in the above framework (see Figure 3). The majority of the research study papers reviewed were found by searching the refereed sources such as the *International Conference on Design and Technology Educational Research* (IDATER) database held at Loughborough University each year from 1988-2001; The *International Journal of Technology and Design Education* - a peer reviewed scholarly research journal covering a variety of research aspects of technology and design education; The *Journal of Research in Science and Teaching* - the peer-reviewed journal of the National Association for Research in Science Teaching, that has included many engineering education and technology related research reports; The *Journal of Engineering Education*, a peer-reviewed international journal published quarterly by the American Society for Engineering Education; and the *Journal of Industrial Teacher Education*, a peer reviewed quarterly scholarly journal that has been published since 1963. Additional, non-peer reviewed publications were also reviewed in an effort to include the growing quantity of recent work in the area. While the publication quality of some of these studies may be slightly lower than some of the peer-reviewed studies, it is mostly due to the incomplete nature of the ongoing research effort (interim research reports) or need for finesse in writing. However, these new studies rely on a richer and broader understanding of the underlying cognitive theories of engineering education and benefit from the vastly increased collaboration in efforts and partnerships of experts in the field. This has allowed many of the new researchers to collect larger sample sizes of data with better controls, as well as a wider geographic and social economic demographic. Thus, many new studies and current research efforts were included by reviewing professional conference proceedings of the *American Society for Engineering Education Annual Conference*, the *International Technology Education Association Conference*

(ITEA), the *Pupils Attitudes Toward Technology Annual Conference*, (PATT) - a Netherlands-based international organization that promotes research in technology education. Doctoral research publications of the *National Center for Engineering and Technology Education*, a collaborative network of scholars in technology education, engineering, and related fields from a partnership of seven universities with support from the National Science Foundation, have also been included.

Table 1. Studies Reviewed – Area of Student Impact

	Technological Literacy & Early Career Awareness	**Cross-curricular Learning (Integrated Content)**	**Cognitive Development and Higher-order Thinking**	**Social skills and Cooperative Learning**	**Student Attitude and Motivation**
Anning (1994) Technological capability in the primary school classroom	X		X		
Anning (1999) Drawing Out Ideas: Graphicacy and Young Children			X		
Asunda & Hill (2007) Critical features of engineering design in technology education	X				
Atkinson (1999) Key factors influencing pupil motivation in design and technology			X		X
Atkinson (2007) Why can't I design as well as other people? I thought I understood the process and what was required.			X		
Bame & Dugger Jr. (1989) Pupil's Attitude Toward Technology PATT-USA A first report of findings	X				X
Barak & Doppelt (1999): Pupil's perspective on the most influential characteristics and major outcomes of a rich technological learning environment	X			X	X
Barak & Zadok (2007) Robotics projects and learning concepts in science, technology and problem solving		X	X	X	
Barak & Zadok (2007) The role of reflection in a technological activity			X		X
Barlex & Trebell (2008) Design-without-make: challenging the conventional approach to teaching and learning in a design and technolog classroom			X	X	X
Barron, Kennedy-Martin, Roberts (2007) Sparking self-sustained learning: report on a design experiment to build technological fluency and bridge divides	X		X		X

Benson & Lunt (2007) ‘It puts a smile on your face!’ What do children actually think of design and technology? Investigating the attitudes and perceptions of children aged 9-11	x				x
Bers & Kahn (2005) An Examination of Early Elementary Students’ Approaches to Engineering			x	x	
Bloom, Carpinelli, Hirsch, Kimmel, & Rockland (2007) The Differential Effects of Female Only vs. Co-ed Enrichment Programs on Middle School Students’ Attitudes to Science, Mathematics, and Engineering	x				x
Bodner, Delgado, Fornes, Giordano, Hutchinson, Krajcik, Shin Hong, Stevens, & Yunker, (2007) Secondary Students’ Beliefs about their Interests in Nanoscale Science and Engineering	x				x
Brophy & Evangelou (2007) Precursors to Engineering Thinking (PET) Project: Intentional Designs with Experimental Artifacts (IDEA)	x		x		
Burghardt & Krowles (2007) Enhancing Mathematics Instruction with Engineering Design	x	x	x		x
Capobianco, Diefes-Dux, & Oware (2008) Gifted Students’ Perceptions of Engineers - A Study of Students in a Summer Outreach Program	x				
Childress (1996) Does integrating technology, science, and mathematics improve technological problem solving? A quasi-experiment		x			
Childress & Rhodes (2006) Engineering student outcomes for grades 9-12	x				
Chunawala , Khunyakari, Mehrotra, & Natarajan (2007) Comparison of depictions by middle school students elicited in different contexts			x	x	
Chunawala , Khunyakari, Mehrotra, & Natarajan (2006) Designing design tasks for Indian classrooms			x		
Chunawala, Khunyakari, Mehrotra, & Natarajan (2007) Using pictures and interviews to elicit Indian students’ understanding of technology	x				
Compton & France (2007) Exploring the nature of technology: Students’ intuitive ideas as a starting point	x		x		
Constable (1994) A study of aspects of design and technology capability at key stage 1 and 2			x		
Cox & Elrod (2006) Perceptions of engineering disciplines among high school students	x				
Cunningham Lachapelle, & Lindgren-Streicher (2005) Assessing Elementary School Students’ Conceptions of Engineering and Technology	x				
Cunningham Lachapelle, & Lindgren-Streicher (2007) Engineering is Elementary:	x	x			

Children’s Changing Understandings of Science and Engineering					
Custer, Daugherty, Merrill, Westrick, & Zeng(2007) Delivering core engineering concepts to secondary level students	x				
Defeyter & German (2003) Acquring an understanding of design: evidence from children’s insight problem solving			x		
Denson (2007) African American high school student’s perceptions of engineering and technology education	x				x
Doppelt (2004) Assessing creative thinking in design-based learning			x	x	x
Egan (1999) Children talking about designing: how do young children perceive the functions/ uses of drawing as part of the design process?			x		
Eguchi, Goldman, & Sklar (2004) Using educational robotics to engage inner-city students with technology	x		x		x
Fleer (2000) Interactive Technology: Can children construct their own technological design briefs?			x	x	
Fleer (2000) Working technologically: Investigations into how young children design and make during technology education	x		x	x	
Fleer (1996) Talking Technologically in Preschool and School: Three Case Examples	x		x	x	
Fleer (1992) Introducing Technology Education to Young Children: A Design, Make and Appraise Approach	x		x	x	
Fleer (1999) The science of technology: Young children working technologically			x	x	
Foster & Wright (2001) How children think and feel about design and technology: two case studies	x		x		x
Ginns & Norton (2005) Exploring the impact of pedagogic approaches in technology practice upon the construction of feminine identity	x				x
Ginns, Norton, & Mcrobbie (2005)_ Adding value to the teaching and learning of design and technology	x	x	x		
Hampson and Ritchie (1996) Learning in the making: A case study of science and technology projects in a year six classroom.	x	x	x		
Hill & Kelley (2007) Cognitive processes of students solving technical problems			x		
Hiltunen & Jarvinen (1999) Home security- Children’s innovations in action	x		x	x	x
Hobbs, Perova, Rogers, & Verner,(2007) Teaching Basic Cardio-Vascular Mechanics With LEGO Models:A High School Case Study	x	x			
Holland & Berlin (2007) Development of technological literacy in gifted and talented elementary school students	x			x	

Hynes (2007) Impact of teaching engineering concepts through creating LEGO-based assistive devices	x				x
Hughes (2007) What informs pupil’s perceptions of technological literacy and capability? An investigation into pupil’s situated knowledge	x				x
Ikonen, Rasinen, & Rissanen (2007) Two experimental learning arrangements in technology education: exploring the impact of the Finnish national framework curriculum on technology studies	x				
Jarvis & Rennie (1998) Factors that Influence Children’s Developing Perceptions of Technology	x				
Knight, Sullivan, Wiant, Yowell, & Zarske (2007) The TEAMS Program: A Study of a Grades 3-12 Engineering Continuum	x		x		
Lehrer & Schauble (1998) Reasoning about structure and function: children’s conceptions of gears			x		
Lyons &Thompson (2006) Investigating the long-term impact of an engineering-based GK-12 program on students’ perceptions of engineering	x				x
Lyons &Thompson (2005) A study examining change in underrepresented student views of engineering as a result of working with engineers in the elementary classroom	x				x
Martinez Ortiz (2008) Engineering design as a contextual learning and teaching framework: How elementary students learn math and technological literacy	x	x			
Miyakawa, Nakashima, & Tsuzuki (1999) A fundamental study on fostering creativity in technology education-Fostering creativity in productive practices using two teaching subjects			x		
Martin (2007) Role of product evaluation in developing technological literacy	x		x		
Mawson (2007) Factors affecting learning in technology in the early years at school	x		x	x	x
McLaren (2007) Exploring creativity and progression in transition through “assessment is fr learning”	x		x		
Mioduser& Betzer(2006) The contribution of Project-based-learning to high-achievers' acquisition of technological knowledge and skills.	x		x		
Mioduser, Levy, & Talis (2007) Episodes to scripts to rules: concrete-abstractions in kindergarten children’s explanations of a robot’s behavior			x		
McRobbie, Stein, & Ginns (2001)* adults title?			x	x	x
Murphy & Hennesy (2001) Realising the potential- and lost opportunities for peer collaboration in a D&T setting				x	x

Miyakawa, Nakashima, & Tsuzuki (2007) A fundamental study in fostering creativity in technology education fostering creativity in productive practices using two teaching subjects			x		
Norton (2007) The use of design practice to teach mathematics and science	x	x	x		
O’Conner (1996) Using the design process t enable primary aged children with severe emotional and behavioral difficulties (EBD) to communicate more effectively	x			x	
Orr, Quinn, &Rulfs (2007) Assessment Results from a Three-Year Project to Teach Engineering in Grades K-6	x		x		
Rogers & Wallace (2000) The wheels of the bus: children designing in an early years classroom			x	x	
Roschelle (1992). Learning by collaborating: convergent conceptual change.			x	x	
Roth (1996) Art and artifact of children’s designing: A situated cognition perspective			x	x	x
Roth (1995) From “wiggly structures” to “unshaky towers”: Problem framing, solution finding, and negotiation of courses of actions during a civil engineering unit for elementary students		x	x	x	
Roth (1995) Knowing and interacting: A study of culture, practices, and resources in a grade 8 open- inquiry science classroom guided by a cognitive apprenticeship metaphor		x	x	x	
Roue (2007) Young women’s perceptions of technology and engineering: factors influencing their participation in math, science and technology?					x
Rowell (2002) Peer Interactions in Shared Technological Activity: A Study of Participation			x	x	
Schauble (1991) Students’ transition from an engineering model to a science model of experimentation		x	x		
Schell & Wicklein (1993) Integration of mathematics, science, and technology education: A basis for thinking and problem solving		x	x	x	x
Smith & Wicklein (2007) Essential aspects and related academic concepts of an engineering design curriculum in secondary technology education	x	x			
Volk (1999) Academic Banding and Pupil’s Attitudes Toward Technology: A Study of Hong Kong’s Selective School Structure	x				x
Welch (1997) Year 7 students use of three-dimensional modeling while designing and making			x		

Research Evidence: Impact on Students' Early Career Awareness & Technological Literacy Development

An early example of a K-12 engineering career awareness effort in the United States is the Junior Engineering Technical Society (JETS), a national organization dedicated to providing engineering and technical career awareness and program support to students since the early 1950s (JETS, 2007). Similarly, the Society of Women Engineers (SWE), founded in 1950, also aimed to provide career awareness regarding engineering, but focused its mission on supporting women to achieve their full potential pursuing careers in engineering and other technological leadership roles (SWE, 2007). In 1970, the national association of college minority retention (later called NACME) established as its mission to provide leadership that would support the increased representation of African American, American Indian, and Latino women and men in STEM careers. Success was measured by improving the level of representation of students enrolling in engineering colleges. This growth was quick to follow and by 1991, African American freshman enrollment had increased by fourfold, and American Indian and Latino freshman enrollments increased tenfold (NACME, 2004). Since then, programs such as the Detroit Area Pre College Engineering Program (DAPCEP) and The Mathematics, Engineering, Science Achievement Program (MESA) continue to promote the involvement of minority students in engineering and science by hosting and facilitating in-school, after-school, and summer learning programs that prepare children as young as kindergarten and up to high school age for future engineering careers while also improving student technological literacy (MESA, 1999).

More recent research in this category has to do with the impact of engineering education programs on students as measured by students' changing levels of awareness and interest in engineering careers as well as their growth in understanding key elements of technological literacy, including basic definitions and understanding of technology and engineering (Barak & Doppelt, 1999; Barron, Kennedy-Martin, Roberts, 2007; Custer, Daugherty, Merrill, Westrick, & Zeng, 2007; Denson, 2007; Foster & Wright, 2001; Ginns, Norton, & McRobbie, 2005; Hiltunen & Jarvinen,1999; Holland & Berlin, 2007; Hughes, 2007; Martin, 2007; Smith & Wicklein, 2007; Volk, 1999). Students' intuitive ideas regarding the nature of technology are limited in both depth and breadth (Compton & France, 2007) and research studies have documented students' deeper understanding of engineering and technology concepts. For example, researchers show how children progress from a stance of categorizing technology as mostly electrical or computer-based, to recognizing the inclusion of basic technologies as anything that is designed or man-made to solve a specific problem, as measured by student pre-intervention and post-intervention questionnaires (Cunningham Lachapelle, & Lindgren-Streicher, 2005; Martinez-Ortiz, 2008). Research studies that utilize student interviews to examine understanding report that students not only obtain a greater understanding of concepts, but also improve in process understanding and express recognition of other interacting factors of engineering and technology such as the role of society and the impact upon society (Berlin & Holland, 2007). Additionally, research shows students gain increased awareness and interest in pursuing science, technology, engineering, and mathematics careers (Bodner, Delgado, Fornes, Giordano, Hutchinson, Krajcik, Shin Hong, Stevens, & Yunker, 2007; Capobianco, Diefes-Dux, & Oware, 2008).

Research Evidence: Impact on Students' Cross-Curricular Learning

The inclusion of an engineering education curricular program has raised questions by both researchers and teachers regarding the specific content to be taught as well as the process for integrating this additional subject area into an already ambitious K-12 school curriculum. In the UK and Australia, for example, the curriculum learning and testing standards have been driven nationally using a standalone design and technology (D&T) curriculum. In the US, where states manage their own education programs, there has been no similar separate curriculum distinction and even in states like Massachusetts, engineering and technology education are grouped with the science learning standards. So, in the US, there has been a particular interest in finding the overlap between engineering and science, engineering and math, engineering and technology, and even engineering and reading and social studies. Engineering curricular units and engineering activities have been developed and introduced in multidisciplinary elementary classrooms and in the math and science classrooms of the older grades (Chalufour, Hoisington, Moriarty, Winoker & Worth, 2004; Childress, 1996; Martinez-Ortiz, 2008; Norton, 2006; Roth 1995; Schell & Widmer, 1993). Research has shown that engineering education can serve as a vehicle to teach other content such as mathematics and science in a cross-curricular fashion (Cross, 1998).

Engineering curricula have been found to impact learning in content areas such as mathematics and science (Childress, 1996; Schell & Widmer, 1993) and to serve as a vehicle for teaching mathematics and science (Ginns & Norton, 2005; Sterling, 2000). The National Science Education Standards and Benchmarks for Science Literacy (American Association for the Advancement of Science, 1993) call for a learning environment that is student centered and engages students in asking their own questions and designing experiments to solve problems. They also call for students to make physical system models that demonstrate their learning and understanding (National Committee on Science Education Standards and Assessment & National Research Council, 1995). Engineering education has facilitated meeting these objectives and has resulted in novel curricular approaches that have formally structured activities and learning objectives around state curricular standards in mathematics and/or science (Benenson, 2001; Bottomley, Brigade, Coley, Deam, Goodson, Kidwell, Linck, Parry, & Robinson, 2001; Cyr, 1999). The development of engineering artifacts has been shown to be an effective strategy for including hands-on inquiry based projects in the elementary, middle school, and high school curricula. In a study by Childress (1996) to determine if an integrated science and math engineering curriculum could be more effective than a stand-alone engineering curriculum in supporting students' solving of engineering design problems, an experimental group of seventeen students and a control group of sixteen eighth grade students were recruited. Student solutions to the engineering challenge posed (related to the design of wind collectors) were analyzed for correctness and quality of their responses to a problem-solving instrument. The researcher also examined whether or not students were attempting to apply the science and mathematics they learned by reviewing the mathematical and science terminology utilized during the second iteration of student problem solving, and their problem solving approaches. This study is valuable in that it piloted a quantitative analysis model for questions of learning in engineering curriculum research and identified some limitations and opportunities for improving this line of research. The students' effectiveness in solving the given problem was determined by measuring the actual performance of the student designed products (wind collectors) based on a content-linked rubric. Although this baseline study revealed no significant difference between those who received integrated science and mathematics instruction (the experimental group) and those who did not (the control group), there was evidence that the students in the experimental group attempted to apply what they learned as evidenced through researcher observation and follow-up student interviews. Additional instruments in general mathematics and science content knowledge would have been important to measure the impact of the learning experience and the impact upon academic content learning in mathematics or science. Evidence of application of mathematics and science knowledge was provided by both observation of the use of related mathematical formulas and appropriate recall and use of the characteristics of weather phenomena. In addition, interviews with students provided indications that the experimental group students tended to consciously apply learned science concepts to the wind collector problem. It would be interesting to identify and isolate the mathematics and science learning experienced by the students and to utilize appropriate instruments to measure if there were greater knowledge gains in this case due to the engineering task.

Some of the existing research does not explicitly refer to engineering education, but due to the nature of the learning experience and the integrated content learning, it is relevant to present within this review. For instance, a study by Jacobson and Lehrer (2000) involved students using quilt design videos, physical manipulatives, and their own creations while learning about transformational geometry in mathematics. The study involved four classrooms of elementary students and their teachers. The use of physical manipulatives, design for a purpose, and use of mathematics in design closely parallel engineering education units and how they work well when integrating additional content such as geometry. Jacobson and Lehrer showed that two classroom groups in particular displayed greater knowledge acquisition of geometric concepts and they were able to retain these concepts over time.

A recent research case study (Norton, 2008), involving twelve Australian students ranging in school grade levels from year 1 to year 7 documented students' math and science learning as outcomes of an intervention involving engineering. Students worked on design and construction activities related to real-world theme park scenarios that integrated space and measurement mathematics learning topics. The selected mathematics topics were explicitly taught in the course of the day and in addition, connections to the related mathematics content were made to the application or design activities. Norton found, through interviews, journals, and video analysis that students indicated an understanding not only of the associated math topics, but also of the underlying scientific concepts such as energy and change concepts. These concepts were later further elaborated upon by teachers, once the students had already discovered them during their design of the theme parks. The design experiences of these students were very authentic and refreshing. Since the student sub groups were very small, they were able to focus on follow-up design activities of their own "ideation." They visited hardware shops in search of their own choice of materials and visited a real theme park to study rides by taking video and photographs that served for future analysis and "backwards-design." Students were instructed in the use of real construction tools such as electric drills and drawing and diagramming techniques. Student improvement was measured in three ways: 1) using pencil and paper grade level appropriate tests on the concepts of space, measurements, and location; 2) student use of mathematical and scientific terms in contextual settings; and 3) student discourse through peer interviews. Students were found to have increased levels of understanding of design as well as the targeted math and science concepts and additional numeracy and science concepts.

The above studies confirm the feasibility and value of integrating engineering along with the teaching of science and mathematics in the elementary and middle school curriculum. In the already busy curriculum of the elementary and middle school student, the synergies of the common underlying principles of these academic areas (communication, problem solving, and justification) and the related nature and interdependency of designing include relevant topics of science, mathematics and engineering. Integrating these can prove to be efficient, effective, and motivating. Engineering education has the potential to fit into existing curricular objectives in both science and math as recommended by Burghart (2000):

> The connections to national learning standards in science and mathematics are direct. There is no need to displace curriculum or squeeze children's engineering into the school day; it fits nicely within the existing science program and has the added benefit of interconnecting with other areas of study, e.g. reading, writing, mathematics. The design process is inherently constructivist--it cannot be prescriptive and be design. It is the belief of many elementary school science educators that a constructivist learning environment is most effective, fitting with students' developmental learning styles." Burghardt (2000, page 8)

The research reviewed above, as well as the many new studies that utilize engineering design as a platform for teaching cross-curricular topics, report that students not only gain in technological literacy, but also make gains in science and mathematics (Burghardt & Krowles, 2007; Cunningham, Lachapelle, & Lindgren-Streicher, 2005; Davis, Fowler, Islam, Kukreti, Oerther, Maltbie, & Turner, 2005; Martinez-Ortiz, 2008). Engineering education, in the form of LEGO robotics, in particular, has also been shown to support applied mathematics learning and problem solving in areas such as physics and biomedical science (Barak & Zadok, 2007; Hobbs, Perova, Rogers, & Verner, 2007). These research findings should motivate educators and policymakers to include engineering education not only for the goal of improving technological literacy, but also to improve student achievement in science and mathematics. There is even the opportunity to improve students' attitudes and interest in science and mathematics such as found by Burghardt and Krowles (2007) after they analyzed the post-test geometry content gains of fifth grades students learning and using geometry within an engineering education program. Future studies should consider incorporating student control groups in order to validate the student achievement data increases.

Research Evidence: Impact on Student's Cognitive Development and Higher-Order Thinking

Engineering education may also play a role in developing cognitive problem solving skills and fostering the utilization of higher order thinking skills. Studies of children designing and participating in engineering education suggest that higher order thinking skills are employed through the unique approaches taken by young children when designing and problem solving (Amsel, Goodman, Savoi, & Clark, 1996; Fleer 1999; Foster & Wright, 2001; Roden, 1995). The nature of engineering involves the use of artifacts and physical manipulatives that may also serve as contextual scaffolding for mathematics content and for scientific models. These manipulatives thus support students' emerging mental structures allowing students to proceed to utilize higher levels of thinking skills as they test interactions and seek what-if self generated scenarios (Martin & Schwartz, 2002).

Research exploring the cognitive impact of engineering education suggests that such learning experiences can encourage the development of systematic process thinking and problem solving skills while fostering creativity and the utilization of higher order thinking skills (Amsel, Clark, Goodman, & Savoi, 1996; Fleer 1999; Foster & Wright, 2001; Roden, 1995). A base of research in the area of children designing and participating in engineering activities is well established by researchers at the University of Canberra, Australia, headed by Fleer (1992, 1996, 1999). Fleer focuses on engineering in early childhood. In a notable study (Fleer, 1999), the interplay between the design ideas of elementary aged children (5-11) and their engineering activity was explored. The aim of the study was to understand how children work when they are involved in engineering activities. The study included nineteen children involved in a 10-week intervention. Students were encouraged to become involved in engineering thinking, planning, constructing, and designing of a "cubby" enclosure, using an open-ended approach that aimed for children to assume ownership over the task and produce their own design briefs. This open-ended design approach was interesting and necessary for the researcher to disengage the student from an overly structured process that might have inhibited the child's design instincts. Fleer explores the significance of tacit "doing" knowledge in relation to children's design and design questions. She also focuses on children's language and discussion themes in contrast to their material manipulation and structural techniques. Specifically, she posits that an open-ended engineering approach positively affects children's learning. Fleer utilizes Roth's (1995) design brief problem terminology of macro-problems, meso-problems, and micro-problems. After ten weeks of designing and building activities, Fleer concludes that children do not appear to bring predetermined engineering questions to their task; rather, that as children work, they frame and reframe new questions. In fact, she finds a surprising level of sophistication in children's design question formulation. These questions relate to design, structure, materials, fantasy, and social issues. The older children, in particular, were able to support their design briefs with some engineering and practical skills of joining and fastening materials, organizing space, and selecting materials. During her observations, she also highlights the important aspect of "play" in the younger children's work and credits the open-ended environment as one that allows children's engineering and metacognitive capabilities to be assessed. Fleer also notes the mathematical analysis presented by Solomon and Hall (1996) that when children work in engineering, they are in effect involved in making sense of how flat shapes can be bent or folded to make 3-D or space-filling objects. Fleer's study is very intriguing in that it offers an approach and a vocabulary for analyzing young children designing, and it begins to identify the higher order thinking skills such as analyzing, integrating, and evaluating, that are elicited by intriguing open-ended design questions.

Another important study from the London University Institute of Education (Roden, 1995) documents the design and engineering skills demonstrated by children involved in design and building tasks. The study focuses on five and six year old children (children entering kindergarten). The sample included eighteen children divided into three groups by age and experience. Children were provided identical design and technology tasks with minimum teacher interaction. These design and problem solving sessions were audio taped and recorded through observation of approach and conversational interaction. Finally, these actions were coded and analyzed using systemic networks (see Figure 4). This methodology allowed the displaying of relationships between general and specific strategies determined as the children progressed through the engineering design process. It also captures the actions taken in response to challenges along the way.

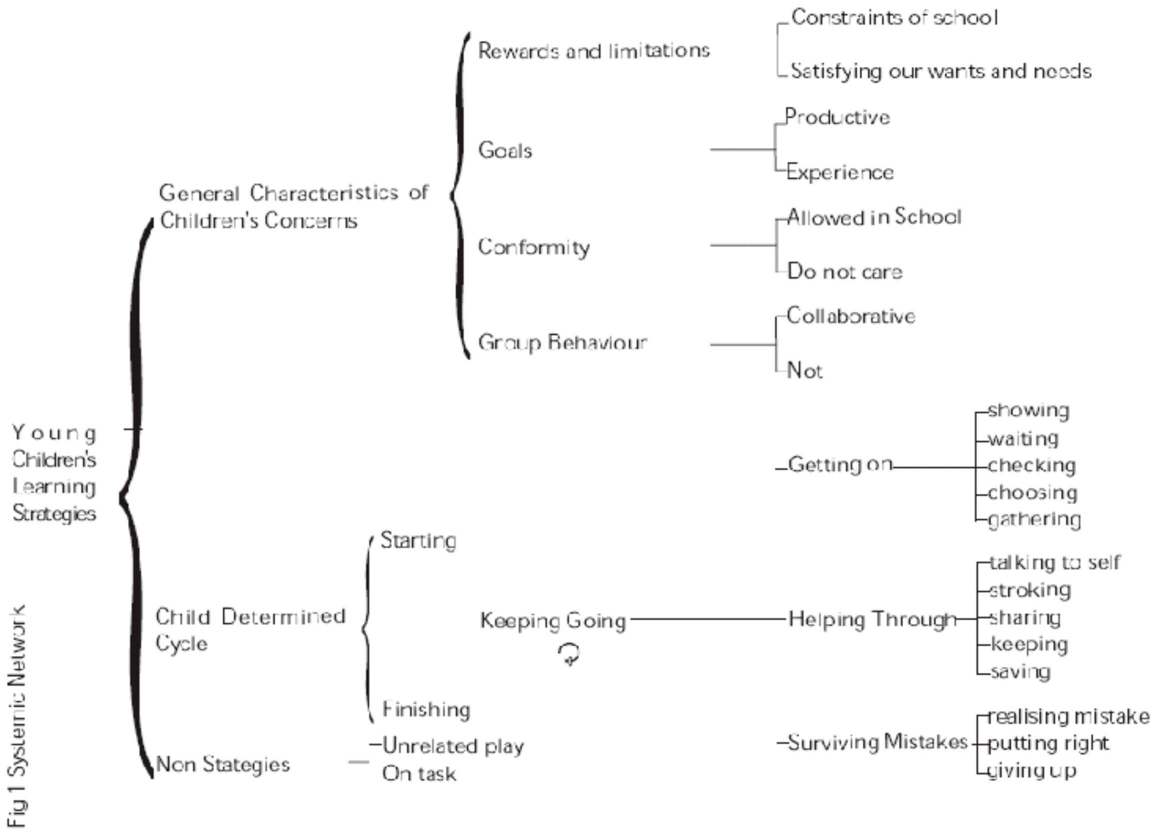
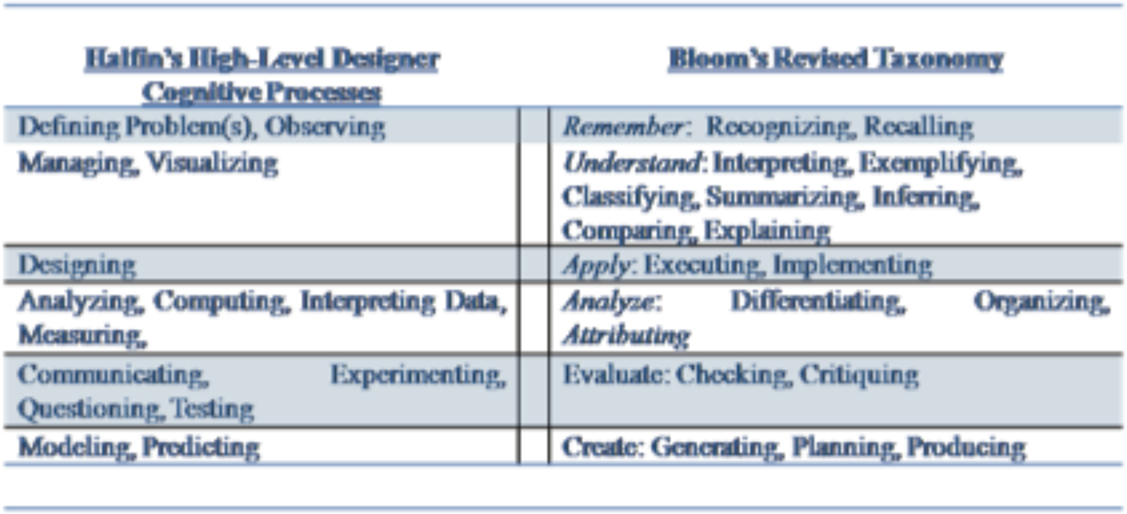


Figure 4. Systemic Networks (Roden, 1995)

Systemic networks as adapted by Roden (see Figure 4) is an observation tool with unique headings that utilize children's own terminology such as "getting on" and "surviving mistakes," as well as cooperative actions observed such as "sharing" and "showing." Through qualitative data analysis, Roden presents generally observed behaviors regarding these groups of children and compares them to each other based on their age groups. Roden (1995) also concludes that the factor of "time" seems important and motivating to children. They have a very strong "productive" concern or interest in getting started making something and an equally strong will to "experience" working with materials, especially those that they highly prize. Roden observed that children indeed come with experiences that include their awareness and respect for "limitations, constraints, and conformity," and they exhibit varying but definite levels of "collaboration" as they share and encourage each other throughout the design process. Roden further suggests that young children may have skills and capabilities that they do not have later in their childhood, mirroring the work on U-shape behavioral growth in children's reasoning and problem solving (Strauss & Stavy, 1982). The systemic network representational tool utilized in this context is an excellent contribution to the field and helps to exhibit the cognitive skills and learning that children experience.

Additional research has been devoted to measuring this cognitive impact by attempting to identify, in-depth, the precise cognitive strategies that a small sample of high school students employed when involved in the design process as measured by the use of verbal protocol analysis and video of the assessment sessions and a computer analysis software tool (Hill & Kelley, 2007). The cognitive processes used in this study as identified by Halfin's (1973) study of high-level designers are shown below (see Table 2) and are contrasted to Bloom's taxonomy of higher order thinking skills (Anderson & Krathwohl, 2001):



Halfin's High-Level Designer Cognitive Processes	**Bloom's Revised Taxonomy**
Defining Problem(s), Observing	*Remember*: Recognizing, Recalling
Managing, Visualizing	*Understand*: Interpreting, Exemplifying, Classifying, Summarizing, Inferring, Comparing, Explaining
Designing	*Apply*: Executing, Implementing
Analyzing, Computing, Interpreting Data, Measuring,	*Analyze*: Differentiating, Organizing, *Attributing*
Communicating, Experimenting, Questioning, Testing	Evaluate: Checking, Critiquing
Modeling, Predicting	Create: Generating, Planning, Producing

Table 2: Bloom's Revised Taxonomy (Anderson & Krathwohl, 2001)

The change from nouns to verbs in the revised taxonomy is significant because it emphasizes the active role of the learner as they 'remember,' 'understand,' 'apply,' 'analyze,' and 'create' (Anderson & Krathwohl, 2001). The classification of intellectual behavior using these terms is also reminiscent of the learning actions involved in engineering design. In the engineering design process, the first steps involve 'identification' and 'researching' the need or problem– which is similar to the actions in Bloom's categories of remembering and understanding. This is followed by 'developing' and 'testing' the best possible solution—which is similar to the categories in Bloom's taxonomy of applying and analyzing. Then, in engineering design, the student will construct a prototype to test and evaluate such as in Bloom's category of evaluating. Finally, this is followed by 'communicating' and 'redesigning' the best possible solution—which is similar to the final category in Bloom's taxonomy of creating new knowledge. The higher order thinking skills of analyzing, evaluating, and creating in Bloom's taxonomy parallel the defining engineering and design thinking skills of the same names. This implies that engineering education activities may offer students additional opportunities to employ and finesse these higher order thinking skills.

Researchers have prioritized seeking evidence on the cognitive impact of engineering education as evidenced by the increase in research studied in this category (Doppelt, 2004, Miyakawa, Nakashima, & Tsuzuki, 2007; Mclaren, 2007; Orr, Quinn, & Rulfs, 2007). Research in this area is very promising and indicates that engineering education, as both a content area and especially as a process area can deliver very important benefits in the development of student higher-order thinking skills. There is also an indication that an increasing number of researchers are utilizing well thought-out, empirical research design methodologies supported by research based assessment tools. The use of qualitative design and analysis is more common (Chunawala, Khunyakari, Mehrotra, & Natarajan, 2007), data collection instruments are more robust and include a variety of components such as questionnaires, student pencil and paper productions, and observations from field notes, multi- media recordings of the student collaborative engagement (Barlex & Trebell, 2008) and one-on-one interviews (Martinez-Ortiz, 2008). The use of much larger samples sizes (Cunningham & Lachapelle, 2005; Volk, 1999) and trials repeated over a greater span of time (sometimes years) (Barak & Zadok, 2007). There is also a great awareness for analyzing gender differences (Roue, 2007; Barron, Martin, & Roberts, 2007), and a greater diversity in the age (Levy, Mioduser, & Talis, 2007; Mawson, 2007), social economic status (Bottomley, Brigade, Coley, Deam, Goodson, Kidwell, Linck, Parry, & Robinson, 2001) and culture of students (Avery & Denson, 2007). These efforts indicate a positive contribution towards the improved quality of research in the field of engineering education.

Research Evidence: Impact on Student's Social Skills and Cooperative Learning

The process of engineering is a non-linear series of steps that requires teamwork, conversation, and self-directed approaches. Research exploring the social impact of engineering education suggests that such learning experiences promote student supported learning and collaboration (Atkinson, 1999; O'Connor, 2000). In one research study, students involved in an engineering experience involving task orientation and decision making were found to exhibit increased motivation and peer collaboration (Murphy and Hennessy, 2001; Rowell, 1999, 2002). However, researchers caution that this collaboration and motivation is also a combined result of the nature of engineering education and the trusting and open classroom learning environment established by the teacher and school. When this is lacking, the flexible nature of design and engineering problem solving is blocked and students may begin to feel a formulaic, non-creative, and stifling environment that limits the natural openness and socially cooperative nature of student engineering design and problem solving.

The hands-on learning and cooperative inquiry-based nature of engineering experiences has motivated some research involving children with severe emotional and behavioral difficulties. Given researchers' experience regarding the way in which engineering projects have enhanced the role of speaking and listening skills and collaboration among students, the question arose as to whether the engineering process and skills could be used to help students improve their more general communication skills. In a UK study (O'Conner, 2000), a teacher-researcher conducted a study that included eight fifth grade students. Four of these students were students diagnosed as having Attention Deficit Hyper-Activity Disorder (ADHD) and Attention Deficit Disorder (ADD), two students were diagnosed as having Asperger's Syndrome, and the other three were victims of traumatic physical abuse or neglect. These students were challenged to work in two small groups designing and making a space food container to be used for food storage during a space journey. They were provided constraints and certain instructional guidelines. O'Conner showed student progress in specific communication skills and thus concluded that engineering education had a positive contribution for encouraging the development of communication and collaboration skills. Results for regular education and gifted education children are similar (Holland & Berlin, 2007; Hynes, 2007; Roth, 1996; Rowell, 2002).

In another study (Schell & Widmer, 1993), student participants of the Mid-American Multidisciplinary Project were interviewed to determine the degree to which the integration of engineering education, mathematics, and science helped them to develop their thinking and problem-solving skills. In addition, their perceptions of these multi-disciplinary projects were collected using a questionnaire instrument. The sample consisted of 148 junior and senior high school students who participated in multidisciplinary projects at four schools in the US. Actual content learning was not measured, but findings showed that students perceived and credited these multi-disciplinary projects in helping them to better understand the integrative relationship among math, science, and technology and allowed them more opportunities to collaborate and learn with their peers.

Rowell (1997, 1998, 1999, 2002) has compiled a substantial amount of research regarding young children's approaches to problem solving in the engineering curriculum setting. Her theoretical basis is a socio-cultural Vygotskian perspective; thus, she focuses on the social interaction in children's learning as it is mediated by language. In one sample study, Rowell examines the nature of participation in an engineering task through close observation of and interviews with two female sixth grade students (Rowell, 2002). Their task was as follows:

> Make a robot which has eyes which light up and can be turned on and off.
> Use as many of the materials as you need. There are more materials here
> than you need. (Rowell, 2002, p. 32)

The students were given a class period of 45 minutes in which to complete the design task. They were provided the materials and were encouraged to draw a picture of what their robot would look like, prior to beginning construction. The pair of students proceeded to work on the task. Analysis focused on their discourse, decision-making, and interactions during this shared task. Rowell notes that part of the interaction had to do with the self-motivated establishment of complementary roles and identities. Students also cooperated and assumed tutoring roles as needed. Rowell notes the importance of materials in the engineering technology design task. These materials serve as mediators of the students' participation and help to shape how the students choose to contribute and share in an activity. The most insightful conclusion found by Rowell in this study is her spotlight on the important and critical role of language as conversation in the context of students working with materials. Many experienced teachers, researchers, and engineers confirm that learning by doing, or "making" is an essential quality in engaging students in participatory learning, but it is the conversation which gives shape to cooperative participation and learning (Medway 1994). Through this research, engineering education is shown be benefit the students by supporting the development of collaboration and communication skills. These skills are important, as emphasized by the Partnership for 21st Century Skills (2008), who outline a subset of skills that are important for students to develop in order to be successful citizens and employees in the 21st century. These skills are grouped into three major areas: creativity and innovation skills; critical thinking and problem solving skills; and communication and collaboration skills.

A similar study by Murphy (2001) also examines student collaboration. This empirical study involved two boys aged 13 working together along with their teacher in the design and construction of an assistive device over an eight-week period. The students utilized an engineering design process to progress through the various design stages in order to complete a useful product. The researchers conclude that although this particular case had many lost opportunities for peer collaboration, collaboration can be accomplished successfully in the D&T setting of "joint design, planning, and problem-solving activities" (Murphy & Hennesy, 2001, p. 203). In addition to the direct study findings, the authors present a very useful outline of optimal pre-conditions for collaboration in the D&T classroom (Murphy & Hennesy, 2001):

> 1. Teacher commitment to supporting learning through collaboration and understanding of collaboration as a learning mechanism.
>
> 2. A task context that sets the conditions for joint decision-making during design and construction.
>
> 3. School and classroom organization which supports small groups including enough time to do so, consistency between classrooms in fostering collaboration, and reinforcement of the value of collaboration through evidence of teacher collaboration.
>
> 4. A range of pedagogic strategies supporting collaboration.
>
> 5. Students' perspectives including shared frame of reference, personal authenticity and social skills and cognitive strategies for collaboration. (p. 208)

This strand of research indicates that the social nature of engineering education and the important role of conversational language not only prepares students to work together as a team of true engineers, but may advance learning as peers teach and clarify engineering concepts and approaches. Many other studies document the enthusiasm and student collaboration exhibited when working on engineering projects (Hampson & Ritchie, 1996).

Research Evidence: Impact on Student's Attitude and Motivation

Engineering education has been found to offer opportunities for increased feelings of self-efficacy (Atkinson, 1999; Kimbell & Perry, 2001; Murphy & Hennessy, 2001; Rowell, 2002). These feelings may stem from the satisfaction students find as they realize the extent of their knowledge and the freedom to employ creative approaches to their problem solving. However, in order to realize the greatest impact, the engineering education learning environment must be supportive of student creativity and self-directed inquiry. Atkinson (1999) demonstrates the negative effects of a non-supportive environment, with a recent study on student motivation.

The purpose of the study was to examine the relationship between student motivation and student performance in design and engineering schoolwork. In addition, student cognitive style, student creativity, teaching strategy, and teacher motivation were examined. The sample included one hundred twelve 15 to 16-year-old students (85 boys and 27 girls) and their teachers in eight targeted schools. This sample was reduced to 50 students (36 boys and 14 girls) by selecting students using a matrix to match students to eight student types based upon student cognitive style, their ability to design, and their perceived enjoyment of designing and creating. Students completed pre and post questionnaires and were observed on a regular basis in their D&T class lessons. In addition, a computer based cognitive style analysis (Riding, 1991) was used. This tool assessed two cognitive style dimensions (wholist-analytic and verbal-imagery) and helped to classify the fundamental ways of student thinking and working. Two additional instruments used in this study were a goal orientation test used to assess behavioral characteristics associated with accomplishing personal goals based on an index designed by Altman (1986).

Researchers found there to be a positive relationship between a student's ability to perform and their level of motivation. This positive relationship was revealed by such factors as student ways of thinking and working, personal goal orientation, and task appropriate skills. However, the data did not reveal the same case for creativity and motivation, although a student's level of creativity was found to relate positively to performance. The authors suggest that the rigid structure of the D&T curriculum and examination model is frustrating for many students and negatively affects both their creativity and motivation. It was also evident that external factors such as delivery programs, as well as teaching strategies, affected the results.

So, engineering education has a great potential to impact students positively by instilling early awareness of their own abilities in science, technology, engineering, and mathematics, and building a self-motivation towards participation in these endeavors through increased self-confidence and skill development. Students as young as five years old have the capability to be engaged in engineering activities by using their intuitive design and creativity abilities to learn technological literacy skills (Compton & France, 2007). The artifacts designed by the children demonstrate the powerful ideas that are brought to life by students' "engineering" through conceptual ideation, collaboration and communication, and physical manipulation (Bers & Kahn, 2005). Engineering education has been shown to positively affect student attitudes and motivation towards science, technology, engineering, and mathematics and to be particularly effective in reaching young girls and students from underprivileged social economic backgrounds (Bloom, Carpinelli, Hirsch, Kimmel, & Rockland, 2007; Cox & Elrod, 2006; Davis, Fowler, Islam, Kukreti, Oerther, Maltbie, & Turner, 2005).

Discussion and Proposed Next Steps

The goal of this literature review was to bring to light the findings of educational research efforts that examine the impact of involving elementary through high school aged children in engineering educational experiences. A review of the related definition terms of 'design education,' 'technology education,' 'design and technology education,' 'engineering technology,' 'engineering design,' and 'engineering education' was presented and an argument was made to adopt the broadest of these, 'engineering education' as the unifying term to be utilized in reviewing the research for this paper. In fact, the field would be well served to come together in agreement of definitions and use of one similar unifying term in an effort to strengthen and focus the mission of better understanding, sharing, and progressing in both research and practice-based knowledge stemming from national and international efforts of the ‘Industrial Arts’ or ‘Tech-Ed,’ ‘Design,’ ‘STEM,’ and ‘ Engineering’ research basis.

There are many needs and calls for additional research in the many sub-areas of engineering education research. The motivation for this is loudest as expressed by the general society and business community that seeks to provide improved academic preparation for students in order to guide and groom students as future citizens that will lead global efforts in innovation, economic competitiveness, and social and environmental stewardship. This is clear, understandable, and common across the many nations involved in improving engineering education and educational practices as students become prepared for twenty first century careers that are largely technologically based and require advanced science and mathematics skills. However, there is also the education community’s intrigue to better understand student learning in both concept and process areas of engineering education. Many look at engineering education as a constructivist instructional approach that may well serve as the platform for providing inquiry-based, project-based learning with real-world and socially responsible hands-on approaches that also supports collaborative, communication-based problem solving, and the development of higher order thinking skills while using technology and developing a technologically literate society. A set of overarching research questions that motivate this call for more research were presented and discussed: (1) How and what do students learn when they are involved in engineering education?; (2) What are the various areas of impact and benefit that engineering education has on students?; (3) What approaches are fundamental for effective engineering education and for assuring teacher preparation in the area of engineering education?; (4) What is the potential of engineering education for students to strengthen skills in related areas such as mathematics and science?; (5) What is the extent to which engineering education might help students develop competencies in technological literacy and interest in STEM careers? In order to explore these research questions, a framework for the impact of engineering education upon students was presented and research in each area was reviewed. The five areas reviewed in this framework included 'early career awareness and technological literacy,' 'cross-curricular learning,' 'cognitive development and higher order thinking,' 'social skills and cooperative learning,' and 'student attitude and motivation.'

Meta-studies examining the efficacy of engineering education still maintain that there is much more to learn and to research in the field and call for more coherent research efforts (Householter, 2007; Lewis, 1993; Petrina, 1998; Soloman & Hall, 1996; Zuga, 1994). As was reviewed in the introduction, this incoherence has existed due to the separate research silos that have existed until now, between those researching "design and technology education," those researching "technology education," those researching "applied science and math education," and those researching "engineering education." In addition, curriculum development work in the field of K-12 engineering education in the past seems to have not been consistently focused on the K-12 grade population. However, the review of research that has now been presented has argued for the adoption of a broader yet clearer definition of what qualifies as engineering education research and has utilized an organizing framework with distinct categories of potential benefits of engineering education: 1) early career awareness; 2) cross-curricular learning; 3) cognitive development and higher-order thinking; 4) social skills and cooperative learning; and 5) student attitude and motivation (Amsel, Clark, Goodman, & Savoi, 1996; Atkinson, 1999; Barlex & Pitt, 2000; Cross, 1998; Fleer 1999; Foster & Wright, 2001; Hill, 1990; O'Connor, 2000; Roden, 1995, Rogers & Portsmore, 2004; Rowell, 2002; Murphy & Hennessy, 2001). Finally, the inclusion of recent collaborative research efforts begins to weave these components together and offers a very optimistic view of the potential benefits of engineering education. In the last five years, there has been a substantial, organized engineering education research effort. Many of the new contributors in this effort are engineering, education, and engineering education graduate students. While in the past many curriculum development efforts were launched without thoughtful partnering research efforts, this is now changing. Curriculum efforts are being organized on a large scale and are guided by the very much needed educational research in all of the areas noted in the engineering education impact framework. Constant and professional leadership is now being provided by professional organizations through organized research efforts and knowledge sharing vehicles such as web-based resources and local, national, and international conferences. One of the recurring recommendations for future research is a call to explore the extent to which engineering education impacts students' cognitive development (Barlex, 2000). Clearly, engineering education at the K-12 level impacts students in many positive ways and the strand of research evidence on cognitive benefits is beginning to be more and more convincing. However, more research on the effective use of appropriate research instruments that quantify the cognitive impact of the engineering technology curriculum, and the impact or connections made to integrated content knowledge is still needed. Engineering education has the opportunity to gain a more solid theoretical grounding by engaging in revealing analytical work and research on the consonance of cognitive science and the instructional models of engineering education.

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