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Articles

Curricular Value and Instructional Needs for Infusing Engineering Design into K-12 Technology Education

David K. Gattie and Robert C. Wicklein

Introduction

An overarching objective of Technology Education in the U.S. is to improve technological literacy among K-12 students (DeVore, 1964; Savage and Sterry, 1990; International Technology Education Association, 1996, 2000, 2003). This is addressed in part through a focus on end-product technology and the use and importance of various technologies in society (Savage and Sterry, 1990). While such a focus is certainly necessary, it may not be sufficient if the objective is to infuse engineering into the technology education field. Current efforts at the University of Georgia propose adjusting the focus of Technology Education to a defined emphasis on engineering design and the general process by which technology is developed. Such an emphasis has the potential for providing a framework to: 1) increase interest and improve competence in mathematics and science among K-12 students by providing an arena for synthesizing mathematics and science principles, and 2) improve technological literacy by exposing students to a more comprehensive methodology that generates the technology. This will inherently raise mathematics and science requirements for technology teachers and technology teacher educators. Moreover, general textbook and instructional material needs for teaching technology education with an engineering design focus will undergo change.

Among the National Science Board's key recommendations in its report on the science and engineering workforce is an emphasis on in-service training and support for pre-college teachers of mathematics, science, and technology as an integral part of the scientific and engineering professions (National Science Board, 2003). This recommendation emphasizes a critical need to develop experiences for K-12 students in engineering. Furthermore, it accentuates the

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necessity for long-term opportunities to prepare in-service teachers in the synthesis of mathematics, science and engineering. This paper proposes the field of technology education as fertile ground for developing an institutional, systemic approach to the needed synthesis of science, technology, engineering, and mathematics (STEM) in K-12 education.

Technology education as a specialized area within the field of K-12 education has undergone a metamorphosis over the past two decades with respect to guiding principles, objectives, purpose, and goals. Early foundations were based on industrial arts with the objective to educate high school students in aspects of an increasingly more industrialized society. The name technology education was officially adopted by the primary professional association, the International Technology Education Association, on February 20, 1985 to reflect the field's transition toward an educational focus on the technological underpinnings of society (Phillips, 1985). To a certain extent, this transition reflected an effort within the general K-12 educational scheme to prepare non-college bound high school graduates to directly enter the workforce with a suite of technological skills. Each transition in the growth and development of the field was accompanied by an appropriate shift in the educational schema for teacher educators and in-service teachers.

Current issues of concern for the overall academic K-12 education subjects have developed due to low nationwide performance in mathematics and science subjects, and a general absence of K-12 programs that motivate and prepare students to consider engineering as a career option (Dearing and Daugherty, 2004). Recently, the field of technology education has attempted to address these concerns by incorporating engineering concepts into its educational schema, thereby providing a formal structure for synthesis of science, mathematics, and technology. The Standards for Technological Literacy (STL) defines what students should know and be able to do in order to be technologically literate and provides standards that prescribe what the outcomes of the study of technology in grades K-12 should be (International Technology Education Association, 2000). This is a defined set of twenty technological literacy standards grouped into five general categories: 1) the nature of technology; 2) technology and society; 3) design; 4) abilities for a technological world; and 5) the designed world. For each standard, benchmarks of academic achievement have been defined for educational grade levels K-2, 3-5, 6-8, and 9-12. Noteworthy, is the inclusion of "design" as one of the general groups. Grades 9-12 are of particular interest as this is often the point in the K-12 education experience when students begin making long-range plans for attending college or vocational school or for joining the workforce. While this is not necessarily the optimal point for introducing engineering concepts, there is a sufficient structure of technology education to assess teacher perspectives regarding engineering design. It may very well be that in the long term, in order to infuse engineering into K-12, a systemic approach whereby grade levels K-2, 3-5, 6-8, and 9-12 are served with appropriate engineering pedagogy would have the greatest impact. However, this effort focused on 9-12 in order to develop initial insight of well-developed areas within the overall technology education landscape.

While the infusion of design into technology education is being built into several programs across the U.S., the interpretation and meaning of design is not necessarily standardized or formally defined within the technology education field. A particular point of departure among the various programs, however, emanates from varied interpretations of design and the approaches by which design is infused into technology education. While various definitions of design are not the fundamental issue, efforts to infuse engineering design into technology education programs would perhaps benefit from at least a common starting point so that academic and research efforts are normalized. This may also provide clarity for in-service teachers as they change curricula to reflect national needs and trends.

Recently, Wicklein (2006) proposed that the field of technology education adopt an interpretation of design based on the engineering definition alone, and suggested that the most appropriate approach for infusing engineering into technology education is by establishing engineering design as the focus. The basis for the assertion is fivefold: 1) engineering design is better understood and valued than technology education; 2) engineering design elevates the field of technology education to a higher academic and technological level; 3) engineering design provides a defined framework to design and organize curricula; 4) engineering design provides an ideal platform for integrating mathematics, science and technology; and 5) engineering provides a focused career pathway for students. Additional efforts in the infusion of engineering design into technology education have been established in a growing number of university instructional programs (e.g. Utah State University; The College of New Jersey; The University of Georgia, Illinois State University, Brigham Young University, and Virginia Polytechnic Institute and State University**)**. In particular, the National Science Foundation's funding and establishment of the National Center for Engineering and Technology Education (NCETE), a collaboration of nine institutional partners focused on infusing engineering design into technology education, reflects commitment at the highest levels. Moreover, fledgling efforts exist within K-12 education and teacher educator environments in the U.S. to prepare teachers and students for teaching and learning technology from an engineering design perspective, with various methodologies for doing so.

As such a redirection that infuses engineering design into technology education would represent fundamental change within the field, general challenges have been identified which will require an assessment of the current state of the field as well as an assessment of the impending needs that will accompany the change. These challenges reflect the authors' experiences and discussions with in-service teachers and technology teacher educators who are working to infuse engineering design into technology education. The general challenges for technology education associated with this fundamental change are identified as: 1) current low-level mathematics requirements in technology education university preparation programs; 2) entrenched traditional views of K-12 technology education as non-college bound preparatory; 3) inconsistent interpretation of engineering *design* within the field ; 4) insufficient instructional resources; 5) inadequate or inappropriate laboratory configurations; 6) negatively biased school decision makers regarding technology education.

Research Goals

This paper presents one element of the University of Georgia's efforts to affect fundamental change based on a national survey of in-service K-12 technology education teachers who use the Standards for Technological Literacy as a guide. Results from the survey are presented and address three areas: 1) the current practices of technology teachers in relation to utilizing engineering design practices within the high school technology education classroom; 2) the value of an engineering design focus for technology education; and 3) the instructional needs of high school teachers of technology education related to engineering design. Results indicate that over 90% of in-service technology education teachers identify engineering design as the appropriate focus for their instructional program, and an equal number recognize that levels of mathematics and science skills, above current requirements, are needed. Moreover, two-thirds identify current technology education teaching materials as inadequate for re-focusing efforts on engineering design. These data provide baseline information reflecting current perspectives of in-service teachers, and give insight into their attitudes about the infusion of engineering design into technology education.

Methods

Survey-based research methodologies were deemed appropriate for collecting data to obtain standardized information from the most knowledgeable subjects integral to this topic. A population consisting of the 1063 in-service high school technology educators who were members of the International Technology Education Association (ITEA) was selected. ITEA is the largest professional educational association, principal voice, and information clearinghouse devoted to enhancing technology education through experiences in K-12 schools. From this population, a stratified, random sample of 583 of these high school teachers was selected, with the four regions of the ITEA serving as the strata. A survey instrument was sent to this sample. These individuals represent a cross-section of high school technology education teachers. However, because the population was delimited to ITEA members only, the results cannot be generalized to the majority of teachers who are not members. A total of 283 usable surveys were returned for analysis through the efforts of an initial and follow-up survey probe, and represented a 48.5% return rate: 104 (36.7%) from the East region, 67 (23.6%) from the East Central region, 76 (26.8%) from the West Central region, and 36 (12.7%) from the West region). Four subject areas were evaluated: 1) demographics; 2) current instructional practices; 3) value of engineering design for the technology education curriculum; and 4) instructional needs related to teaching engineering design. These areas reflect concepts developed from the authors' professional experience, discussions at workshops and conferences, and feedback from various focus groups. The areas are necessarily broad by design as this study represents an initial step toward developing a broad vision of the technology education landscape with respect to the needs associated with engineering design. The instrument was carefully written so that the meaning of engineering design was clearly defined, and all answers were based on a common foundation. The following statement was provided on each page of the survey instrument:

> 'Engineering Design' Defined:
> Engineering design, also referred to as technological design, demands critical thinking, the application of technical knowledge, creativity, and an appreciation of the effects of a design on society and the environment. The engineering design process centers around four (4) representations used to describe technological problems or solutions: (1) **Semantic** – verbal or textual explanation of the problem, (2) **Graphical** – technical drawing of an object, (3) **Analytical** – mathematical equations utilized in predicting solutions to technological problems, (4) **Physical** – constructing technological artifacts or physical models for testing and analyzing (International Technology Education Association, 2000; Ulman, 2003).

Results

Respondents were predominantly male (87.2%) teaching at the high school level (92.5%) with an average of 17.4 years of teaching experience and an average age of 47. Only one-fourth (25%) have B.S./B.A. level degrees in technology education, while 43.8% have undergraduate degrees in industrial arts. About two-thirds (65%) have masters degrees, of which over half (59.2%) are in areas other than technology education and industrial arts (see Table 1).

The vast majority (90%) indicated that topics on engineering or engineering design are currently being taught in their courses with 45.4% of instructional content devoted to the subject. While almost 80% are satisfied with their own instructional methodology, over half (53.2%) are not satisfied with current instructional materials. Most (87.4%) do not identify any constraints to including engineering design content in their curriculum, but only half (54.2%) are aware of local or state approved courses or curricula that focus on engineering or engineering design (see Table 2).

Respondents expressed confidence that an engineering design curriculum focus would add value to the field of technology education by: clarifying the focus of the field (93% agreement); providing a platform for integration with other school subjects (96.7% agreement); elevating the field to higher academic levels (92.7% agreement); improving instructional content (88.4% agreement); increasing student interest in mathematics and science (89.3% agreement); and providing additional learning opportunities for students (94.4% agreement) (see Table 3).

Table 1
Summary of results regarding demographics

Demographic Criteria	Response
Years experience (mean)	17.4
Level at which currently teaching	Middle School – 3.5% High School – 92.5% Other – 3.8%
Gender	Male – 87.2% Female – 12.0%
Average Age	47
College Degrees Obtained	B.S./B.A. 30.0% Masters – 65.0% Ed.S-Specialist – 2.4% Ed.D – 0.3% Ph.D – 2.1%
College Major	B.S./B.A. Level Industrial Arts – 43.8% Technology Education. – 25.0% Other- 31.2% Masters Level Industrial Arts – 16.8% Technology Education – 24.0% Other – 59.2%

Table 2
Summary of results regarding current instructional practices

Survey Item	Response
Do you currently teach topics/courses that are related to engineering or engineering design?	Yes – 90.0% No – 9.3%
What percentage of your teaching instruction is related/connected in any way to engineering or engineering design?	45.4% (mean)
If you are teaching engineering or engineering design how satisfied are you with your current instructional methodology?	Extremely Satisfied – 12.9% Satisfied – 66.0% Dissatisfied – 19.1% Extremely Dissatisfied – 2.0%
If you are teaching engineering or engineering design how satisfied are you with your engineering related textbooks or text materials?	Extremely Satisfied - 2.8% Satisfied – 44.0% Dissatisfied – 41.2% Extremely Dissatisfied – 12.0%
Are you under any administrative (local or state) constraints to limit/exclude engineering or engineering design instructional content in your technology education curriculum?	Yes – 12.6% No – 87.4%
Are you aware of any local or state approved course(s) or curriculum that has a focus on engineering or engineering design?	Yes – 54.2% No – 45.8%

Table 3
Summary of results regarding the value of engineering design for technology education. Emboldened values indicate highest level; italicized values indicate second highest level.

An engineering design curriculum would:	**Strongly Disagree**	**Disagree**	**Agree**	**Strongly Agree**
	n(%)	***n(%)***	***n(%)***	***n(%)***
Help clarify the focus for technology education	2(0.7)	17(6.3)	**152(56.3)**	*99(36.7)*
Increase the overall academic value of technology education	0	14(5.1)	**131(48)**	*128(46.9)*
Provide a platform for integration with other school subjects	1(0.4)	8(2.9)	**139(50.5)**	*127(46.2)*
Elevate technology education to higher academic levels	1(0.4)	19(7)	*113(41.4)*	**140(51.3)**
Elevate technology education to higher technological levels	1(0.4)	15(5.5)	**129(47.6)**	*126(46.5)*
Provide a more focused career pathway for students	4(1.5)	31(11.7)	**145(54.9)**	*84(31.8)*
Improve the academic value of technology education in the minds of students	2(0.7)	34(12.6)	**130(48.1)**	*104(38.5)*
Improve the academic value of technology education in the minds of parents	1(0.4)	16(5.7)	**132(49.1)**	*120(44.6)*
Improve the academic value of technology education in the minds of school administrators	5(1.8)	18(6.7)	*115(42.9)*	**130(48.5)**
Improve the instructional content for technology education	2(0.7)	29(10.9)	**142(53.2)**	*94(35.2)*
Improve coverage of technological literacy content within technology education	0	30(11.3)	**141(53.2)**	*94(35.5)*
Increase student interest and appreciation for mathematics and science	3(1.1)	25(9.5)	**129(49.2)**	*105(40.1)*

Table 3 (continued)
Summary of results regarding the value of engineering design for technology education. Emboldened values indicate highest level; italicized values indicate second highest level.

An engineering design curriculum would:	**Strongly Disagree**	**Disagree**	**Agree**	**Strongly Agree**
	n(%)	***n(%)***	***n(%)***	***n(%)***
Provide additional learning opportunities that would open career options for students	0	15(5.5)	**150(55.1)**	*107(39.3)*
Elevate the technology teacher as a more valued member of faculty	2(0.8)	49(18.9)	*92(35.5)*	**116(44.8)**

Table 4
Summary of results pertaining to instructional needs to support the teaching of engineering design. Emboldened values indicate highest level; italicized values indicate second highest level.

My instructional needs to teach engineering design include:	**Strongly Agree n(%)**	**Disagree n(%)**	**Agree n(%)**	**Strongly Agree n(%)**
	n(%)	***n(%)***	***n(%)***	***n(%)***
Identifying appropriate instructional content	4(1.5)	20(7.3)	**167(61.2)**	*82(30)*
Determining the appropriate level of instruction	5(1.9)	23(8.6)	**162(60.7)**	*77(28.8)*
Integrating the appropriate levels of mathematics and science into the instructional content	2(0.7)	15(5.5)	**156(56.7)**	*102(37.1)*
Gaining the appropriate levels of mathematics and science knowledge to teach engineering design	5(1.8)	35(12.8)	**136(49.8)**	*97(35.5)*
Locating appropriate textbooks and associated text materials	4(1.5)	24(8.8)	**142(52.2)**	*102(37.5)*

Table 4 (continued)
Summary of results pertaining to instructional needs to support the teaching of engineering design. Emboldened values indicate highest level; italicized values indicate second highest level.

My instructional needs to teach engineering design include:	**Strongly Agree n(%)**	**Disagree n(%)**	**Agree n(%)**	**Strongly Agree n(%)**
	n(%)	***n(%)***	***n(%)***	***n(%)***
Having the appropriate types of tools and test equipment to teach engineering design	1(0.4)	20(7.2)	*110(39.9)*	**145(52.5)**
Having the appropriate type of laboratory layout and space to teach engineering design	2(0.7)	21(7.7)	*111(41)*	**137(50.6)**
Developing additional analytical (mathematics) skills to be able to predict engineering results	3(1.1)	33(12.2)	**151(55.7)**	*84(31)*
Improving fundamental knowledge of engineering sciences (statics, fluid mechanics, dynamics)	5(1.8)	20(7.2)	**149(54)**	*102(37)*
Having access to practicing engineers to give consultation and oversight	2(0.7)	27(10)	**147(54.2)**	*95(35.1)*
Establishing a support system with mathematics and science faculty	2(0.7)	34(12.5)	**148(54.4)**	*88(32.4)*
Garnering the support of school administrators and counselors	5(1.8)	22(8)	121(43.8)	**128(46.4)**
Seeking the promotion of the engineering/engineering design curriculum by school administrators	6(2.2)	18(6.6)	**135(49.6)**	*113(41.5)*

Results from the assessment of instructional needs indicate that the in-service technology educators in the sample recognize the need to improve their own level of knowledge pertaining to engineering design subject matter. With respect to integration of appropriate levels of mathematics and science into their instructional content, 93.8% recognize this as a need, and 85.3% acknowledge that gaining the appropriate levels of mathematics and science knowledge to teach engineering design is necessary. Moreover, 86.7% agree that developing additional analytical (mathematics) skills and 91% agree that improving fundamental knowledge of engineering sciences are needed to teach engineering design appropriately at the high school level (see Table 4).

Discussion

A comparison of the technology education design process, as defined by the Standards for Technological Literacy, with a general description of the steps involved in the engineering design process, reflects a fundamental distinction with regard to mathematics and analysis (Table 5) (International Technology Education Association, 2000; Eide, Jenison, Mashaw, and Northup, 2001). It is noted that the engineering design process is iterative and not strictly linear, although the categories in the figure reflect the general steps involved. The technology education design process is directed toward the construction of a prototype model that can be tested for failure or success, but lacks the mathematical rigor that would enable the process to be repeated. Moreover, the absence of analysis precludes the development of predictive results. This fundamental difference is the basis for change within the current technology education framework suggested in this paper, and is reflected by the survey results.

Table 5
A comparison of design processes

Engineering Design Process (Eide, et.al., 2001)	**Technology Education Design Process** (ITEA, 2000)
1. Identify the Need	1. Define problem
2. Define Problem	2. Brainstorming
3. Search for Solutions	3. Research & Generate Ideas
4. Identify Constraints	4. Identify Criteria
5. Specify Evaluation Criteria	5. Specify Constraints Explore Possibilities
6. Generate Alternative Solutions	6. Select an Approach
7. Analysis	7. Develop a Design Proposal
8. Mathematical Predictions	8. Build a Model or Prototype
9. Optimization	9. Test & Evaluate the Design
10. Decision	10. Refining the Design
11. Design Specification	11. Communicating Results
12. Communicate Design Specifications	

While 90% of the technology educators surveyed teach topics or courses in or related to engineering or engineering design, the mathematics requirements for undergraduate degrees in the technology education field are typically not beyond college algebra or trigonometry. This apparent paradox may help explain why 85% of the respondents also recognize that improvement in analytical skills, science knowledge, and engineering science is necessary for them to teach engineering design adequately. This is also a reasonable basis upon which to question the levels to which formal engineering design is being integrated into the K-12 experience in the U.S., even among those who make the effort to do so. At the undergraduate level, introductory engineering design is taught at the freshman level with a minimal mathematics requisite or co-requisite of differential calculus. Concepts of rates, limits, and maximum/ minimum are already being instilled and can be drawn upon as the college engineering curriculum advances through integral and vector calculus, differential equations, and linear algebra. At least one major challenge confronting efforts to infuse engineering design in K-12 education is the development of a pedagogical framework that builds upon a mathematical foundation that begins with elementary algebra and culminates with calculus. This framework will also entail the need for novel instructional materials that creatively develop the concepts of engineering design in K-12 without sacrificing the critical steps of engineering analysis. It is plausible that this indicates a level of dissatisfaction with current technology education instructional materials and textbooks. At least one reason for this dissatisfaction could be that a focus on technological literacy alone is inadequate for teaching analytical methodologies of engineering design.

While the STL's (Standards for Technological Literacy) include references to design, "engineering design" is mentioned in only one of the standards, while mathematics and science are not mentioned at all. This may lead to a fuzzy, non-focused basis for infusing engineering design into technological literacy. STL standard #3 states, "Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study." The benchmark for this standard is given as, "Technological progress promotes the advancement of science and mathematics." This implies that science and mathematics are closely related to technology. However, this relationship is realized only through the engineering design process that produces the technology. The need for and usefulness of science and mathematics are not comprehended through technological literacy alone. However, the engineering design process that develops the technology offers a framework within which science, mathematics, and technology can be pedagogically contextualized and analysis can be integrated directly. Survey respondents recognize this as evidenced by their support for an engineering design focus as a platform to integrate technology education with other school subjects such as mathematics and science. Within technology education, the current focus on the technology produced by the engineering design process engenders a certain level of technological literacy, but does not necessarily synthesize mathematics and science in that focus.

Standard #8 states, “Students will develop an understanding of the attributes of design,” followed by standard #9 which states, “Students will develop an understanding of engineering design.” In both cases, mathematical analysis is not mentioned as a benchmark for any of the K-12 grades. Since these are standards to which in-service technology educators adhere, these two standards might foster a variety of interpretations of design. As mathematics and science are not listed as benchmarks for either standard # 8 or #9, it is difficult to understand the role of engineering design within technology education. In light of this, respondents appear to agree that engineering design is the appropriate approach for clarifying the focus of technology education.

Conclusion

Within science education, the scientific method is as necessary as the scientific principles. We propose a parallel line of reasoning for the engineering and technology education wherein the design methodology that produced the technology is as important as the artifact of technology itself. Respondents to this survey agree that an engineering design focus for technology education would be a valuable contribution, although they realize their own limitations due to academic training and educational resources. However, the results of this study are not proposed as a sufficient edict on the current landscape of technology education; rather, it serves as a step toward a more lucid view of the landscape and into how well-prepared in-service teachers see themselves for teaching a design methodology that includes mathematical analysis. Infusion of engineering design into technology education will require a steady, focused effort. This effort, however, is not simply to draw students into engineering careers. Rather, it is viewed as a contribution to the K-12 education system in general as it provides the opportunity for students to realize the usefulness of and need for mathematics and science as they apply to their lives through technology, understanding it within the context of the engineering design methodology.

The benefits of an engineering design focused curriculum for technology education have potentially broad ramifications. If done deliberately and with academic rigor, technology education can be identified in an entirely different light. Students and parents will see a curriculum that is organized and systematic, leading to valued career options. School administrators and counselors will have a curriculum that provides multiple options for students, both college-bound and non-college bound. Engineering educators will receive a better-prepared student who understands engineering design processes at the onset of their college experience. Business and industry will have a greater number of U.S. citizens entering the engineering workforce. This is a viable future for technology education and a needed contribution to the engineering profession. The question remains, “Are K-12 and the engineering profession prepared and willing to accept this formidable but worthwhile challenge” (Dearing and Daugherty, 2004, p.11)?

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